JOURNAL OF THE A·I·E·E·

OCTOBER 1925

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PUBLISHED MONTHLY BY THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 WEST 39TH ST· NEW YORK CITY

American Institute of Electrical Engineers

COMING MEETINGS

New York Section, October 23

MEETINGS OF OTHER SOCIETIES

American Electric Railway Association, Atlantic City, Oct. 5-9

Regional Meeting, The American Society of Mechanical Engineers, Hotel Penn-Alto, Altoona, Pa., Oct. 5-7

New York Electrical Society, Engineering Societies Bldg., New York, Oct. 7

American Society of Civil Engineers, Fall Meeting, Montreal, Oct. 14-16

Association of Railway Electrical Engineers, Hotel Sherman, Chicago, Oct. 20-24

American Welding Society, M. I. T., Boston, Oct. 21-23

N. E. L. A.: Southeastern Geographic Division, Chattanooga, Tenn., Oct. 29-30

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York

Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Phillipines, $10.50 to Canada and $11.00 to all other Countries. Single copies $1.00.

Entered as matter of the second class at the Post Office, New York, N. Y., May 10, 1905, under the Act of Congress, March 3, 1879. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918.

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Current Electrical Articles Published by Other Societies

American Electrochemical Society (Advance Copy—Sept. 28, 1925)

A Laboratory High-Frequency Vacuum Furnace, by J. R. Cain and A. A. Peterson

Manufacture of Sodium Nitrite by the Arc Process, by H. K. Benson

Association Engineering Society of St. Louis, July 1925

Spot Welding of Heavy Sections, by J. A. Osborn

Iron & Steel Engineers, August, 1925

Electrical Drives for Rolling Mills, by H. C. Uhl

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Super-Synchronous Motor, by H. C. Uhl

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Auxiliaries and Auxiliary Drives for Steam Electric Generating Stations, by A. L. Penniman

Direct-Current Armature Winding for Multi-Polar Generators and Motors—Frogleg Winding, by W. H. Powell and G. M. Albrecht

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Electric Heat-Treating Furnace Application, by E. A. Hurme

Heating of Ingots by Electricity, by R. A. Butler

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Selection and Maintenance of Oil Circuit Breakers, by M. J. Wohlgemuth and E. K. Read

Selection and Maintenance of Oil Circuit Breakers, by G. A. Burnham

National Electric Light Association, August, 1925

Electrification of Transportation, by P. S. Clapp

Some Phases of the Illinois Central Railroad Company's Lake Front Improvements and Electrification, by D. J. Brumley

Status of the Engineer, by R. F. Peck

Servicing the Railroads, by W. S. Murray

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLIV OCTOBER 1925 Number 10

Engineering and Public Service*

Washington, Franklin, and Jefferson were born engineers. Washington loved mathematics; he started his career as a state surveyor, and no man without a genius for solving difficult engineering problems would have succeeded as Washington did in organizing the Continental Army which he led so successfully from the beginning to the end of the American Revolution in spite of the many almost insurmountable difficulties. Franklin's devotion to science and constructive engineering work, particularly during the early period of his life, is well known. A student of Jefferson's life says that as a student at the College of William and Mary he had acquired "a familiarity with higher mathematics and natural sciences, only possessed, at his age, by men who have rare natural taste and ability for those studies." When Jefferson retired from the political arena he devoted himself entirely to engineering work. The physical structure of the University of Virginia was the result. An incident will be mentioned now which indicates that during the formative period following the War of American Revolution, there was an engineering mind which steered the course of the American ship of state.

After the signing of the treaty of Peace with Great Britain in 1783, anarchy and chaos threatened the newly born United States. They were held together by the Articles of Confederation as long as they faced a common enemy. But as soon as the enemy had disappeared, each State thought more of its own sovereignty than it did of the loosely constructed Articles of Confederation and of the Union, which was so strongly advocated by Washington, Franklin and by other patriots. It was clear that a new and obviously national problem was needed, the solution of which would appeal to all States alike, and would demand a united national effort. The navigation of the territorial waterways and all the technical and economic considerations connected with it was such a problem. Commissioners were appointed by the legislatures of Virginia and Maryland to form a compact relative to the navigation of the rivers Potomac and Pocomoke and part of the Bay of Chesapeake. They met at Alexandria in 1785, and during a friendly visit to General Washington at Mount Vernon, their problem, as well as their ideas, became greatly enlarged. They recommended that another meeting be held at Annapolis a year later, and that it should be attended by commissioners from all other States. This idea was undoubtedly suggested to them by Washington. The meeting was held and adjourned to meet again at Philadelphia in 1787. This resulted in the Federal Convention in Philadelphia the president of which was General Washington. It framed the Constitution which transformed the political and economic chaos of that critical period into a cosmos.

Observe now that navigation of the waterways in its broadest aspect was essentially an engineering problem; the search for a solution was undoubtedly steered by Washington, an engineer. The several attempts to solve it attracted public attention in all the States and prepared public opinion to recognize that there must be a united national effort whenever a result of general national importance was aimed at. In response to this recognition the States sent their delegates to the Philadelphia Convention which, under the presidency of an engineer, Washington, and guided by the wise counsel of another engineer, Benjamin Franklin, framed the Constitution. It was, therefore, the mental attitude and the resourcefulness of the engineer which blazed the way and helped to save the situation at the most critical moment in the early history of the United States. What are the services which the mental attitude of the scientist and engineer rendered during the succeeding periods of American history?

It would be superfluous to discuss here the well-known services which the engineer rendered during the first half of the nineteenth century when this nation was busy reclaiming the wilderness of the vast territory between the Atlantic and the Pacific. Nor is it necessary to say anything about the well-known services which the scientist and the engineer rendered during the second half of the nineteenth century, the transition period of the United States from the purely agricultural pursuits to mining and industrial activity.

But a brief review of the achievements of science and engineering in this country during the last fifty years should be given here. This is the period of the American Rennaissance; the manifestation of that new freedom which Lincoln prophesied in his Gettysburgh speech. It was inaugurated immediately after the Civil War by a movement in the direction of higher intellectual endeavor of which Johns Hopkins University is the earliest visible monument. This university, the first real American university, became the earliest nursery of higher intellectual pursuits and scientific idealism. Today there are scores of American universities which are following the noble example of Johns Hopkins University. Scientific idealism has been transplanted by American university men ot

*Address delivered by President Pupin over telephone wires from New York to the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 17, 1925.

American industries, and today the most precious asset of this nation is the unity of purpose of our science, engineering, and the industries. Scientific research and development, and scientific idealism are the cement which binds these three branches of the American intellect into one inseparable unit. The achievements resulting from their united effort furnish the most convincing proof that their mental attitude and their method of procedure are the best guarantee of success in all human activities. What is their method and mental attitude? Watchful observation, careful experimentation, scrutinizing calculation, honest open-mindedness. Is this the method and the mental attitude which we have adopted in other departments of our national activities? Has, for instance, our political and our ecclesiastical machinery adopted this method and mental attitude? If they have not, and if the results of their methods offer inadequate protection to the safety of our democracy, who is called upon to preach to them the gospel of moral and political salvation? Who else than the men who belong to that distinguished guild which is the guardian of our American science, engineering, and the industries? Does this mean that men trained and disciplined in the pursuits of science, engineering, and industries should step beyond the limits of their favorite activities and enter fields which naturally belong to the politicians and the theologians? It does; did not Washington, Franklin, and Jefferson perform a similar public service?

The telephone, the phonograph, electrical lighting and electrical transmission of power, the gas engine, the automobile, and the flying machine, the moving picture, and radio broadcasting are all products of the last fifty years. They are among the most conspicuous contributions of our science, engineering, and the industries to the material wealth and comfort of our nation. But how much moral force and efficiency have they added to our political administrative machinery and particularly to the administrative machinery of our municipalities? How much have they aided the influence of the church? How much help have they furnished to the efforts to raise the moral standards of the American communities? How much wealth have they contributed to the spiritual resources of this nation and of the world? Many persons who are ignorant of the aspirations of the scientific mental attitude will say: "Nothing!" and they will say it without the slightest hesitation. They share in the belief of Gogol, the gloomiest of the gloomy Russian pessimists. Gogol maintained that science is a witch who knows the secrets of nature and in league with matter, is seeking to destroy the influence of the Holy Spirit. This is Gogol's description of what he called "the baneful influence of scientific materialism." When one considers the abuses of the several blessings mentioned above, which science, engineering, and the industries during the last fifty years, have conferred upon human society, he will admit that Gogol's gloomy picture is not quite so unreal as appears at first sight. The horrors of the World War and of its after effects, both here and abroad, force us to this admission. But these abuses are not an indictment against the scientific mental attitude and the scientific method which created these blessings; they are indictments against the mental attitude and the method of the organizations which control the political and the spiritual activity of all nations including our own. Let them adopt the mental attitude and the method of our great national guild which is the guardian of our science, engineering, and the industries, and whose component parts are cemented into an inseparable unit by that intellectual idealism which was born at Johns Hopkins University fifty years ago. We members of this guild are called upon today to advocate the universal adoption of this idealism which is the moving force in our triumphal advance. This is the only way leading to a complete demonstration that the spirit of science, engineering, and the industries is in league with the Holy Spirit, and not against it as the pessimists of the Gogol type believe. This is a new service which our discipline and training can contribute to the safety of our American democracy.

M. I. Pupin

Some Leaders of the A. I. E. E.

Samuel Sheldon, the nineteenth president of the A. I. E. E., was born on March 8, 1862, at Middlebury, Vermont, where he was graduated from Middlebury College in the year 1883 with the degree of A. B., receiving the A. M. degree in 1886, and the honorary degree D. Sc. in 1911. At college he was the winner of the Waldo prize for four years, was salutatorian of his class at graduation and received the highest honors in physics.

He next took up graduate work at the University of Wurzburg, Germany, receiving, in 1888, its Ph. D. degree. Returning to the United States, Dr. Sheldon became assistant in physics at Harvard University. Later he was appointed professor of physics and electrical engineering at Polytechnic Institute of Brooklyn, where he remained until his death, September 4, 1920.

Dr. Sheldon was the author of four standard works on electrical machinery and engineering and wrote numerous technical papers on various phases of electrical engineering work.

He was president of the New York Electrical Society, 1902-03; president of the John Fritz Medal Association, 1910; trustee of the United Engineering Society and chairman of its Library Board, 1916-17. The honorary degree, Dr. Sc., was conferred upon him in the year 1906 by the University of Pennsylvania.

Dr. Sheldon was a member of many of the national and international technical and physical societies. He was president of the A. I. E. E. throughout the term 1906-07.

Fundamental Considerations of Power Limits of Transmission Systems

BY R. E. DOHERTY[1]
Associate, A. I. E. E.

H. H. DEWEY[1]
Associate, A. I. E. E.

Synopsis—*At this time the power limit of transmission lines is a live subject and presents such complications as to require very careful analysis. The paper points out the essential features to be considered in a study of the problem, and calls attention to some outstanding results of an experimental investigation of the subject with a view to clarifying some of the points that have been under discussion in the past two years.*

It is shown that the problem of stability is not necessarily confined to long-distance, high-voltage transmission, but may be present in any system where the impedance of the transmitting circuit is high compared with the load to be carried.

While the impedance of the transmission line and transformers plays an important part in establishing the breakdown point of a system, the characteristics of synchronous apparatus with the method of voltage regulation used are of equal importance.

It is shown that the synchronizing power of synchronous apparatus is largely dependent upon the field excitation at the time excess load is applied; that field excitation is determined by the circuit conditions under steady load, and, in order to provide for increase of excitation with increasing loads of considerable magnitude, some automatic means of controlling the field is essential.

The rate at which mechanical load in large quantities can be added to a system is limited on account of the necessity of change in angular displacement between the generators and receiving bus; this changing angle requires relative speed change, which takes time. This fact, together with the inherent tendency of synchronous machines to "stiffen" under sudden applications of load, makes it possible to rely on the usual vibrating-type voltage regulator working on the field of the exciter to provide the necessary field change. It is brought out that the maximum load that a system can carry under steady conditions at normal voltage can be suddenly thrown on, and the voltage regulator, with the assistance of the factors mentioned, will provide the necessary excitation.

Voltage regulators are practically a necessity where it is desired to approach, under operating conditions, the ultimate maximum power of the system.

Transient load changes that occur on the usual system, such as throwing on or off load, cutting in or out transmission circuits, etc., can be easily taken care of, providing such changes do not exceed the steady state limits of the system.

The effect of short circuits depends upon their nature, whether three-phase or single-phase, and upon the location and duration. This subject is discussed briefly and the conclusion drawn that successful operation can be obtained under usual short-circuit conditions if adequate relaying is provided.

The possibility is discussed of increasing the limit of power transmission by improving the apparatus and the characteristics of the transmission circuits, and it is pointed out that no great development may be expected from any scheme yet proposed regarding a modification in line characteristics. With reference to the apparatus, it is possible to make some changes in the design of synchronous machines tending to "stiffen" them, such as higher saturation, larger air-gap, etc., but in general no radical improvement may be expected here that does not materially increase the cost and decrease the efficiency of the machine. Attention is turned therefore toward such schemes of regulation, or compensation, of the synchronous apparatus as would increase the maximum power. Among these is the use of reactors for locally controlling power factor and thus too the field excitation of the more important synchronous machines. However, the possible additional power thus obtained is limited, and, as it now appears, other methods which have greater promise will be resorted to.

The use of a mercury-arc rectifier in the alternator field circuit seems to have great possibilities. By varying the field current in rigid proportion to the armature current, a very significant degree of compensation of the armature reaction is obtained—about 50 per cent, which is, of course, equivalent to almost doubling the inherent capacity of the generator. While this scheme is not yet in practical form, its efficacy has nevertheless been demonstrated in factory tests, and it is regarded by the authors as one of the most promising developments at this time.

* * * * * *

The problem of power limits of transmission systems has within the last few years assumed importance in the study of long distance transmission of large blocks of power. Fundamentally there are no new elements entering into the use of long lines operating at high voltage that would be disturbing were it not for the fact that economic considerations require an approach closer to the maximum power which it is possible to transmit than has been the case in most of our existing systems.

In general, the problem is not confined to long distance transmission, but is one that may be met at any time where the impedance of the circuit from the scource of power to the point of consumption is comparatively high. There have been a number of isolated cases cited wherein the limit of stability has been reached and synchronous systems have pulled apart, where no great distance of transmission was involved. The growth of power networks is now so rapid, with interconnections that will require transfer of such large amounts of power, that it is essential that the principles on which stability of operation depends be thoroughly understood.

The rapidly increasing demand for electric power requires extensive development of our national resources with consequent growth of long distance transmission. The economical use of our water power, as well as mine mouth steam plants, makes it necessary to keep the investment in transmission lines as low as possible, which involves carrying the maximum amount of power feasible over each line with due regard given to continuity of service. Matters of efficiency and regulation can be met by well-known methods and the question of the maximum amount of power that can be transmitted over a single circuit becomes one of stability

1. Both of General Electric Co., Schenectady, N. Y.

Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

of the line with its connected apparatus. It is necessary, therefore, that all the factors entering into the problem be thoroughly well known and appreciated, as errors may be extremely costly both in investment charges and quality of service.

While great stress has rightly been laid on the limiting effects of long lines as a determining factor in stability, it is nevertheless true that no general conclusion can be drawn as to the probable limit of power from data regarding the line alone. There are many other elements that assume varying importance with different lengths of lines, such as different characteristics of generating and receiving apparatus, different types of regulating devices, etc.

The papers[2] that have been read and the discussions that have taken place on this subject during the past few years, have shown such varied viewpoints that one who has not made a special study of the subject may easily be confused as to what the real problem is and its practical importance to the industry.

It is the purpose of the authors to outline the underlying considerations of the problem, with particular reference to the factors which determine power limits under various operating conditions, and to cite a few of the more significant results of an extended investigation. The details, both of the methods of analysis and of the calculated and test results, will be presented in forthcoming papers. In other words, the present paper is, to a great extent, merely a statement of the problem, a discussion of the factors involved and an indication of the direction in which the investigation is leading.

Most of the studies of stability of transmission systems that have been made have been on lines of from 300 to 500 miles in length designed to operate at 220 kv. This fact has led, in some cases, to the erroneous impression that there is something inherent in the use of 220,000 volts for transmission purposes that may limit the amount of power which may be transmitted with stability. It should be borne in mind, however, that there is a definite limit of power which may be transmitted over any system regardless of voltage or length of line and it is just as possible to encounter unstable conditions in a line one mile long, operating at low voltage, as it is to encounter it in a long line at high voltage. It is merely a question of how close to the power limit normal operation may bring us.

With a given installation of synchronous apparatus, the amount of power that can be transmitted over a connecting circuit is, generally speaking, decreased by increased impedance and vice versa. With the growth in capacity of some of our large steam generating systems, requiring extensive use of power limiting reactors, it is necessary to take the matter of stability into account and avoid the possibility of too much reactance between large generating stations or even sections of the same station. There are a few well-known cases on record where the power limit has been reached between stations and loss of synchronism with consequent shutdown has resulted. This has occurred in systems operating at all voltages and varying lengths of connecting lines.

The stability problem, then, is not an entirely new one, though cases of trouble from this source have been sufficiently isolated and of such a special nature as to cause little stir among operating engineers.

On extremely long high-voltage lines there is another factor in addition to high impedance that has a tendency to limit the power to be transmitted with a given synchronous installation. The charging current of such lines becomes quite an item and, contrary to that which might be expected, may reduce the maximum power. This is brought about from the fact that, although the charging current reduces the effective impedance of the line, it also lowers the necessary excitation on the synchronous apparatus by reason of the higher power factor. This feature will be discussed later in greater detail. It is practically the only factor in long high-voltage lines tending to affect stability that may not be present in short low-voltage lines.

The matter of charging current may also become important in underground transmission, especially if the voltage of cables is raised materially. While this problem is not before us just now, the tendency toward higher voltage underground may place it there in the future.

An analysis of the problem of the determination of the limit of power on a given system involves a close study of not only the characteristics of the transmission line, transformers, generators, exciters, synchronous condenser and receiving load, but the method of operation and system of regulation as well.

The phenomenon of breakdown of a synchronous motor operated from a bus of large capacity, is pretty well known. If the shaft load of such a motor is gradually increased it will finally reach a point at which no more electrical power can be supplied to the motor, even though the bus voltage remains constant, and the motor will drop out of step. The amount of electrical power which can be supplied to the motor at a given voltage depends upon its internal impedance and its excitation at the time the load is applied. If the excitation remains constant at its no-load value, breakdown will occur at a much lower load than if the excitation is increased.

A synchronous generator functions in a manner similar to a synchronous motor and can be driven out of step with the bus, if a prime mover of sufficient capacity is connected to it. The amount of shaft power necessary to drive the generator out of step with the bus depends upon its internal impedance and the excitation at the time.

If a synchronous generator is used to furnish power to a synchronous motor of the same size and characteristics, and with excitation on each machine correspond-

2. Groups of Papers presented at A. I. E. E. Convention at Philadelphia, Feb. 1924, and New York, Feb. 1925.

ing to no-load normal voltage, then when the shaft of the synchronous motor is loaded, both will drop out of step at a value of load that is approximately one-half of that which either would carry if connected to a bus of the same voltage and of infinite capacity. This is due to the fact that their impedances are in series and of twice the value of a single machine. As the motor is gradually loaded, it drops back in phase position with respect to the generator and drops out of step at a definite angle.

Going a step further; if a synchronous generator is used to supply power to a synchronous motor through a reactor or over a transmission line, there will likewise be

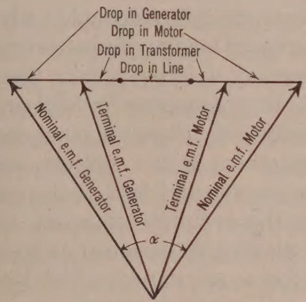

FIG. 1—SYSTEM VOLTAGE VECTORS

a definite breakdown point which, at a given excitation on each machine, will be less than before the reactor or transmission line was inserted. This is, of course, obvious as the line or reactor causes in itself an added impedance drop and an added angular displacement between the generator and synchronous motor. In other words, the power first appears in electrical form at the generator, then successively passes through intermediary apparatus including transformers and line and finally through the motor. That is, it passes through a succession of electric circuits in each one of which, including the generator and motor, the power flow causes an impedance drop. This changes the magnitude and displaces the phase of the voltage as shown in Fig. 1. In the simple case considered, the components of impedance drop add in series, producing a total displacement between the internal, or nominal voltage[3] of the generator and the internal voltage of the motor. The maximum power in this case is proportional to the product of these two voltages, *i. e.*, the field excitations, inversely as the total impedance between them, and occurs when they are displaced by a definite angle which is usually less than 90 deg.

The matter of excitation as noted above is thus one of the greatest importance in the problems of maximum power limit. Indeed, on short lines the difference between the breakdown point with no-load normal voltage excitation and with full load 0.8 power factor excitation may be as much as 100 per cent.

3. Corresponds to the value of field excitation.

At first glance, it may seem a simple matter to provide sufficient excitation to obtain high synchronizing force in the synchronous apparatus, but it is really a rather complicated problem. The excitation for any given voltage at the terminals of an alternator depends upon the power factor of the load. As mentioned above, in the case of the alternator driving a synchronous motor of equal size, there is no leeway at all in the control of the total field excitation of the two machines, if the terminal voltage is held constant. A reduction in the field excitation of the synchronous motor will require an equal addition in the field of the alternator and while one is weakened the other is strengthened a similar amount and no gain results.

In the case of long-distance transmission lines it is desirable, so far as the line is concerned, in order to keep the losses and regulation of the line at a reasonable figure, to deliver power at the receiving end at a high power factor. This results, however, in a high power factor on the generators at any given load and consequent lessening of their breakdown capacity. As a matter of fact, some local low power factor load on the bus at the generating end of a long-distance transmission system may actually increase the maximum power possible over the line by increasing the generator excitation.

In this connection it will be noted that a high power factor load is actually a detriment in so far as it affects synchronizing power; and it is certainly one of the

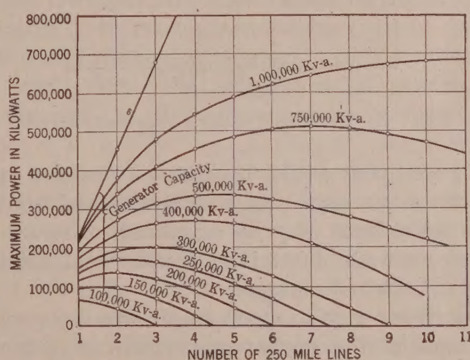

FIG. 2—MAXIMUM POWER WHICH CAN BE TRANSMITTED 250 MILES AT 220,000 VOLTS, SHOWN AS A FUNCTION OF THE CAPACITY OF SYNCHRONOUS APPARATUS, AND THE NUMBER OF TRANSMISSION CIRCUITS

phenomena that should be taken into account in the design of a long distance transmission system. It may come as somewhat of a shock to many engineers who have not made a close study of this problem, to learn that the inherent charging current of a long high-voltage line actually reduces the maximum power that can be transmitted with respect to that which could be carried over a line of similar reactance without charging current. The authors have made actual studies showing that more power could be carried over two high-voltage long-distance lines in parallel than over three with a given

installed generating capacity. This is merely an illustration of the effect of reducing the excitation on the generators by the excess charging current of the third line in a case where the impedance of the generators is an important factor.

Fig. 2 will serve to illustrate this point. It will be noted that for the 250-mile, 220-kv. line considered, there is a definite relation between the installed synchronous capacity and the number of transmission circuits that will give maximum power over the system. In the case of 300,000-kv-a. synchronous capacity of usual design at each end of the line, three circuits will carry approximately 200,000 kw., while five circuits will carry only 160,000 kw. and nine circuits, no power whatever. This effect would be still more pronounced in the case of a 500-mile line.

It has been suggested that the bus at the generating station end of the line be loaded with reactors to allow the transmission line a high power factor load but to lower the power factor on the generators themselves. This would increase the excitation and thus the maximum power that could be taken from the system. This plan shows some real possibilities and under certain circumstances may be employed, although there are other methods of obtaining similar results that may be used to better advantage.

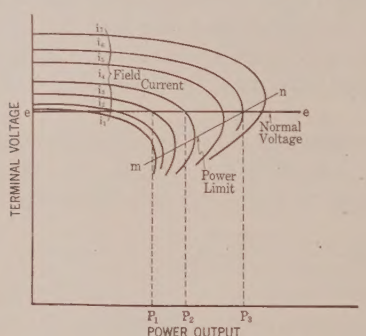

Fig. 3—Typical Voltage-Power Curves

The authors wish to again emphasize the very great importance of the excitation problem as a factor in stability of synchronous machines. Its importance has been recognized before by the authors of previous papers on this subject, but it has not been given quite the prominence that we feel it deserves. Were it possible to absolutely control the field current of synchronous machines as desired, the problem of stability would be very much simplified.

With the importance of field excitation in mind and the knowledge that under fixed conditions of load, voltage and power factor, the strength of the field will also be fixed, it will be seen by reference to Fig. 3 that only a small increment of load may be added without breakdown unless the field excitation is changed. For instance at power, p_1, corresponding to field current, i_3, and normal voltage, e, it would be possible to increase the load about twenty per cent, or if operating at power, p_2, excitation, i_4, the possible increase would be only six per cent. If means are provided, however, to automatically increase the excitation as load increases, the maximum power could be increased to p_3, which is the ultimate maximum that could be transmitted at normal voltage. This maximum could be reached regardless of what load was being carried at the time the increased load came on.

The authors of some of the early papers laid considerable stress on the point that voltage regulators in general use, while tending to follow the load requirements by increasing the field current as needed, were entirely too slow to do so adequately when the time transient of the exciter was taken into account. The argument looked entirely reasonable when it was suggested that increased load might be thrown on instantly, as by dropping off a large turbine generator at the receiving end—thus dropping its load on the transmission line. Fortunately there are compensating features in the characteristics of the system, and the linkage between the armature and field of the alternator make it possible for the ordinary vibrating type of voltage regulator and a properly designed exciter to supply the needed excitation at any rate at which load can come on to the line and generating station.

The explanation of this phenomenon which the authors feel is of the greatest moment, lies in two important facts: First, that large blocks of system load cannot be thrown on the generators instantly, as the angle between the generators and receiving apparatus must increase—this requires a slowing down of the receiving system which, of course, takes time—and second, as load comes on the generators, the sudden increase in armature current induces a field current tending to hold them in step. These two phenomena consume sufficient time to allow voltage regulators and exciters to function, furnishing the necessary field current to maintain voltage at the greater load. A more detailed discussion of this point will be given later on.

This point brings out the very great importance of the use of voltage regulators in a long distance transmission system, as the maximum load safe to carry over a line, from the standpoint of stability, will be increased in some cases more than fifty per cent by their use. This important consideration, in the authors' opinion, has had practical demonstration in some existing systems that have operated for some years without difficulty from lack of stability. Many cases that have come to our attention would be on the ragged edge, if not impossible to operate without voltage regulators.

The foregoing discussion covers, in a general way, the simple case of a generating station feeding a synchronous load approximately equal in kv-a. capacity. For such a case the maximum power is easily calculable and there are no serious problems when the matter of excitation and regulation are understood and properly provided for.

When complications arise, such as the generating

station feeding more than one independent transmission line or when the receiving end is a network with generating capacity and load of its own, the problem becomes difficult. In general, the more synchronous apparatus there is connected to either the generating or receiving-end bus, the more nearly will the maximum power limit of the line itself be approached, because the condition of infinite buses is being approached. Generating stations tapped into the middle of a long line, or synchronous condensers of large capacity used either at the receiving end or in the middle of the line, increase the maximum power that can be transmitted over a given system. The calculation of the actual power limits in such cases becomes very complicated.

During the past year the authors, in conjunction with other interested engineers, have been carrying on an extensive series of tests in the General Electric Company factory on an artificial transmission system equipped with synchronous generating and receiving apparatus, synchronous condensers, voltage regulators, transmission lines, adjustable as to the length, characteristics, etc. With this equipment it has been possible to set up almost any combination of conditions that might obtain in a practical installation and to vary the characteristics of individual pieces of apparatus in any way that might show promise of interesting results.

The experimental work on this artificial system has been paralleled by mathematical analysis throughout and not only has a mass of valuable data been obtained showing the effect of modifications in design or operation of the equipment under varying conditions, but methods have been developed which the writers feel will be of great assistance in the solution of any practical problem. The results of this comprehensive investigation, which is now being completed, will be published in the near future.

In the foregoing, the larger aspects of the problems which have arisen in connection with the development of power transmission in this country have been discussed in a general way, and the situation has been outlined as it exists today with respect to the use of standard apparatus. In that which follows, the problem of possible future increase in power limits will be stated and analyzed in terms of the various factors which determine the present limits and possible solutions will be suggested.

Influence of Synchronous Machines

As already suggested, in those problems in which stability is a practical factor, the outstanding fact is the usually predominating influence of the impedance of the synchronous apparatus. For illustration, consider a 500-mile straight-away transmission line at 220,000 volts. If there were no power limitations in the electrical apparatus at the ends of the line (the conditions usually referred to as "infinite bus"), the power limit of the system, *i. e.*, of the line itself, would then be about 130,000 kw. With synchronous apparatus of the usual design and of the usual capacity with respect to the power to be transmitted, the limit becomes about 70,000 kw., or practically half. This point may be further emphasized by the fact that a few actual proposals have been studied in which the line, less than a hundred miles long, was practically a negligible factor. Hence the power limit is imposed in such cases largely by the impedance of the synchronous machines.

When this fact was first encountered, a number of plans for increasing the maximum power of the system were suggested, but much of the promise of success disappeared upon analysis. Larger generators might be used, but that was too costly. Another line might be added, but that was not only costly but, in the long lines, it actually decreased instead of increased the maximum power. Studies have been made of the use of series static condensers in the line of sufficient size to neutralize, at least partially, the reactance of the line and transformers. Theoretically, there are great possibilities in this scheme as the total reactance of a line of any length can be reduced to a negligible value. The present high cost of condensers together with certain difficulties of operation, render this plan out of the question for the present but it is one worthy of further attention for engineers studying this subject. A scheme[4] was proposed for decreasing the reactance and increasing the capacitance of the line; but although this might improve the line regulation, it did not gain favor, partly on account of the difficulty of construction, but principally because it would further weaken the generators by increasing the charging current. An exciter which would respond very quickly to the voltage regulator might, it seemed, strengthen the generators and thus increase the ultimate maximum power at normal voltage, *i. e.*, greater than p_3 (Fig. 3); but it was early recognized that this could not be accomplished by such an exciter and vibrating type regulator. Such regulation makes it possible, as already mentioned, to carry the ultimate maximum, corresponding to p_3 in Fig. 3, even if this is thrown on the system suddenly—but not significantly more than that. Thus, when all of the above proposals have been analyzed, the situation is not far different from the starting point with respect to increasing the ultimate maximum power under steady operation at normal voltage.

Yet this is what must be done, if it is hoped to transmit power over long lines—500 miles or more—in synchronous operation. There may be some other and better way to do it than in synchronous operation, but, if the latter is to be retained, the problem of increasing the maximum power reduces to one of stiffening up the synchronous apparatus.

Thus, the problem to which a number of interested engineers have been directing their attention has been along two general lines. One has been to "stiffen" the

4. "Output and Regulation of Long Distance Lines," Percy Thomas, A. I. E. E. Trans., Vol. XXVIII, p. 615, 1909.

synchronous apparatus, and thus approach the power limit of the line itself. The other, perhaps looking considerably to the future, has been toward finding some other means than synchronous operation. Regarding the latter, however, there is little of interest, to the authors' knowledge, other than that such studies are being made. In the light of the past growth and the probable future, such limits as that even of the line alone, cannot, of course, be accepted as final. Hence the situation demands such studies. However, the hope of the immediate future lies in the other direction —in finding such modifications and auxiliaries in connection with present synchronous apparatus, including the synchronous condensers, as will make possible a nearer approach to the power limit of the line alone.

The problem of stiffening the synchronous apparatus has been attacked along two general lines. One relates to schemes of regulation of the more important synchronous machines; the other, to modifications in design, which, in effect, would result in machines of higher *inherent* power capacity—that is, lower reactance. The former include the regulation of the field current, the use of shunt inductances across the generator terminals, and any other schemes which would apply to regulating currents from an exterior source. On the other hand. to lower the reactance of the machine itself is, of course, a problem in the design.

Conditions of Operation

Before taking up in detail the questions of design and regulation, it is well to consider the conditions of operation which affect the problem of maximum power. The study of this problem resolves logically into the consideration of two conditions of operation. In one, technically referred to as *steady state*, all forces involved in the entire system are in stable equilibrium. The power flow is everywhere steady; and in the apparatus the voltages, field excitation, magnetic flux, etc., are all constant. Everything is balanced and steady.

In the other, referred to as *transient state*, conditions are changing. Power flow, speed, magnetic flux, voltage—all of these are in a state of change.

Now the maximum power which can be transmitted, and, to a limited extent, the amount which it is necessary to transmit, depend upon the state. If, during steady state operation, a load is suddenly thrown on, or a loaded generator is dropped, or a short circuit occurs, a readjustment or transient must follow in speed, power, voltage, magnetic flux, etc., before steady conditions are again established. During this change, the synchronous apparatus all becomes inherently more powerful, or "stiffer," than in steady state, as explained under *transients*, but, due to possible "overshoot" of power on the swing of load following the shock, the power which must be transmitted may also be increased above that required after the system settles down. If a weight attached to a spring is suddenly dropped, thus stretching the spring, it will drop, on the first swing, not to the steady state position where the spring tension equals the pull of gravity, but will overshoot, throwing additional tension on the spring. If we imagine the stiffness of the spring to increase temporarily during this transient state, the analogy with the present problem would be fairly complete. The maximum power which can be carried is temporarily increased, but the amount which it is necessary to carry is also increased.

Steady State

The steady state operating characteristics of a generator supplying power to a transmission system are shown on Fig. 3. It will be noted that as the field current, shown as parameter, is increased the maximum power—*i. e.*, the limit of stability, where the slope of the voltage-power curves is infinite—is progressively greater, and occurs at successively higher voltage as indicated by the line $m\,m$. Hence there is a particular value of field current, i_6, for which the maximum power occurs at normal voltage. This is obviously the ultimate maximum which the system can carry at normal voltage. While a still greater field current i_7 would give greater maximum power, it would nevertheless occur at a voltage higher than normal.

Influence of Field Excitation

In Fig. 3 it will be noted that operating at power p_1 and at normal voltage e requires a field current i_3. If the power were increased to p_2 without changing i_3, the system would break out of synchronism, since the maximum power with i_3 is less than p_2. Thus, when any system is operating as near the limit as in the above illustration, the field current must be promptly increased as the load is increased, to hold the voltage along the line $e\,e$. The question of the rate at which load can be applied, as well as other transient conditions, will be discussed later. The point to be observed here is that the degree of stability is indicated by the slope of the voltage-power curve; that the maximum power is greater, the greater the field current, and occurs at an ever higher terminal voltage; and that there is therefore one field current i_6 for which the maximum power occurs at normal voltage. And this is the ultimate maximum which can be transmitted under steady state at normal voltage.

It may be further stated as a very important fact bearing on the characteristics of synchronous generators that, roughly, the greater the field current *at the same voltage*, the greater the stability and maximum power, regardless of what means are used to obtain the larger field current. Thus, to lengthen the air-gap of the machine or increase the degree of magnetic saturation, or decrease the power factor of the load by connecting across the terminals a shunt inductance—any of such measures will require more field current at the same load and voltage, and therefore improve the stability and maximum power.

The steady state characteristics of synchronous condensers are, of course, very similar. These comprise a set of curves of the same general form as those in Fig. 3

and involve the same quantities, except that the abscissas are reactive kv-a. instead of active power. Similarly, the maximum value of reactive kv-a. which the synchronous condenser can deliver is progressively higher and occurs at successively higher voltage, as the field current is increased.

Parallel Operation

In both of the above cases, the characteristics are for a single machine. Suppose, for instance, that three or more generators, instead of one, are connected to the bus. Then what are the characteristics? If the units are all alike, including the governor characteristics of the prime movers, and the excitation currents of all units are kept equal, then a similar set of characteristics as in Fig. 3 could be drawn, taking field current as parameter. These would represent the voltage-power characteristics of the bus. In the successive steady state conditions after increments of load are added, the governors have placed correspondingly more power, the regulators correspondingly more field current, on all machines. So they all reach their respective power maximum at the same value.

However, if the units are different, additional parameters are necessary—the governor characteristics and settings for all prime movers, and also the distribution of field current on the several generators. Under this condition, the units do not reach their respective maxima at the same total load. Thus, when there are a number of units in parallel, the steady state limit of the combination is a function of the distribution of load and of field excitation, and also of the governor characteristics. And there is an optimum distribution which gives the greatest power, and this is such that all reach their respective maxima at the same total load.

The same is true of a number of branches of a power network connected to the same bus. Each branch may be from a power bus such as just discussed, involving the parameters mentioned. So while the problem of the extended combination is, of course, still definite, it is nevertheless greatly complicated by additional parameters.

So, in general, systems under steady state operation can be characterized by such curves as shown in Fig. 3. As generators are added, the slope of the curves becomes less, reaching zero with an infinite generator capacity. Up to three or four branches the characteristics are amenable to reasonably definite calculation. Beyond that, resort must be made to simplifying approximations or equivalent circuit tests. Methods of calculating the simpler cases of steady state conditions have been published[5]. Extensions and additional methods will be presented in the near future.

Transients

In transient conditions, many factors, in addition to those which influence steady state operation, are brought into play. Among these are the momentum of rotating masses, and the time element in both the electromagnetic circuits and in the governors.

Sudden Application of Load. In Fig. 4, if load is suddenly thrown on the shaft of the motor, the electrical power to the motor can not increase until the motor drops back in phase, which requires a temporary drop

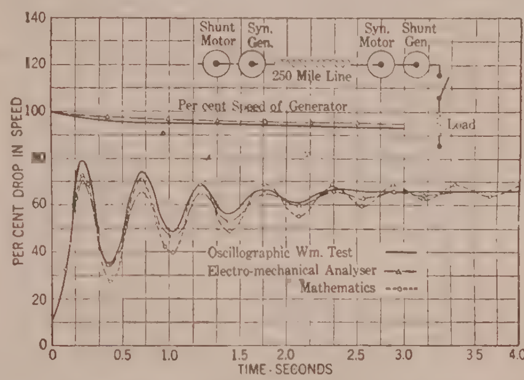

Fig. 4—Transient Conditions Following a Sudden Application of Load

in speed. This means that the initial increased demand was partially supplied from the momentum of the motor, causing the electrical power supply to increase more gradually, thus lessening the shock to the system. Moreover, the load which first falls on the generators is initially supplied from the momentum of the rotors, until the speed drops, after some oscillation, to that value at which there is balance, determined by the governor, between mechanical input and electrical output. Fig. 4 shows the transients for an analogous case as indicated.

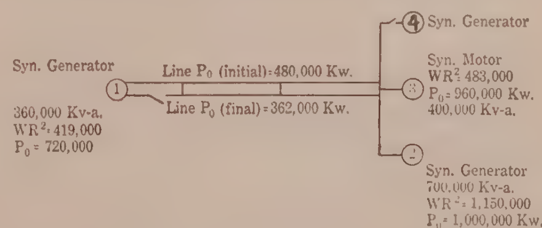

Fig. 5

These curves were obtained by three methods: One by the oscillographic scheme proposed by C. A. Nickle[6], referred to later; another by mathematical calculation, and the third by actual test.

Dropping a Generator. Referring to Fig. 5, with the line section switch closed, and with the following distribution of load, suppose the switch on generator No. 4 is opened:

Synchronous motor No. 3..........	400,000 Kw.
Generator No. 1..................	100,000 "
Generator No. 2..................	280,000 "
Generator No. 4..................	200,000 "

5. Group of papers and discussion by Edith Clarke and C. A. Nickle on this subject presented at the Midwinter A. I. E. E. Convention, Feb. 1924.

6. "Oscillographic Solution of Electromechanical Systems" by C. A. Nickle, A. I. E. E. Convention, Saratoga Springs, June 22-26, 1925.

Fig. 6 shows the nature of the resulting transients.

At first, the power flow and the electromagnetic torque of the various units are quite independent of the torque on the shaft of either the motor or generators which is determined completely by the electrical constants of the system; since due to the inertia of the rotating masses, the relative-phase positions of the rotors remain, for the moment, what they were before the switch was opened. After a transient, the system settles down to power conditions as determined com-

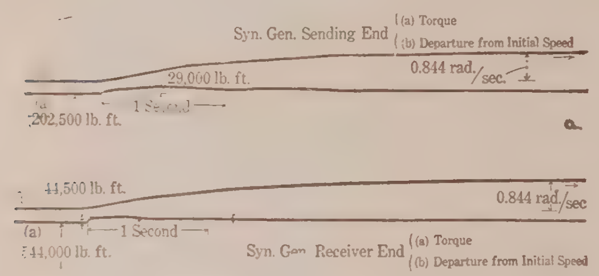

Fig. 6—Transients Due to Dropping Generator No. 4 from System in Fig. 5

pletely by the governor on the prime movers. Thus, in the first moment the power flow is determined by the constants of the electrical circuits, and in the last, by the governors.

Switching out a Section of Line. Another case is that in which a section of line is suddenly opened, as indi-

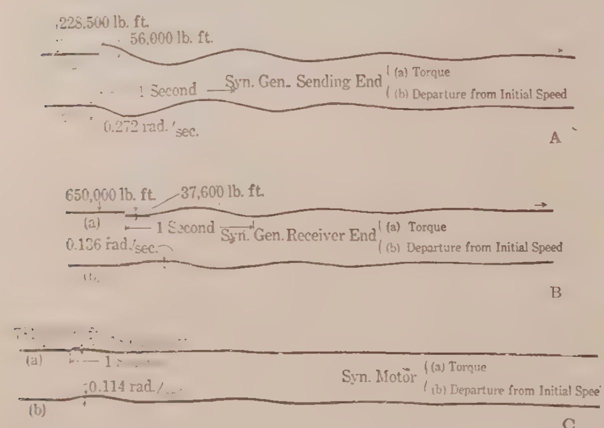

Fig. 7—Transients Following the Switching out of a Line Section Indicated in Fig. 5

cated in Fig. 5. The load distribution is the same as above, except that Generator No. 4 is disconnected. This sudden interposition of added reactance, requires a phase adjustment, which does not increase the steady state load on the system, but it does cause a power oscillation which usually overshoots the steady state value. This contains all of the transient elements discussed above, and is illustrated in Fig. 7.

During the above transients, the time elements of both the governor and the magnetic fields play a part. After load is thrown on a unit, it is a matter of seconds before the governor becomes adjusted to the new condition. Hence, regardless of the sudden load, the flow of water, or steam, as the case may be, is practically the same as before, and in studies of what happens in the first second or so, constant *flow* (not constant torque) is usually assumed.

The magnetic flux linked with the alternator field circuit also does not change in the first moment[7]. The armature currents due to sudden load automatically induce a corresponding m. m. f. in the field to sustain constant flux linkage. If there is no voltage regulator, the flux gradually dies down to steady state conditions, but during the meantime the reactance of the machine is less. It starts as transient reactance of relatively low value, which includes armature and field leakage, and ends as synchronous reactance, which is of relatively higher value and which includes armature leakage and armature reaction, but not field leakage. As already mentioned this inherently stiffens the machine in the first moment. In other words, to speak of the spon-

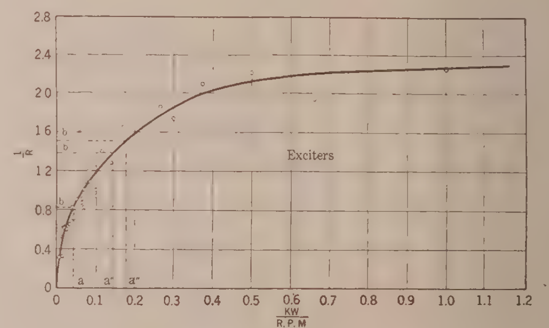

Fig. 8—Curve Indicating the Relation Between the Time Constant and the Speed and Capacity of Exciters

taneous rise in alternator field current following a shock, whether it is a short circuit or a sudden application of load, or to say that the transient reactance applies, is merely to refer to the same phenomenon in different terms.

If there is a voltage regulator, then, as previously mentioned, it is a race between the rate at which the load comes on and rate at which the exciter can build up. As mentioned before, the combination of circumstances attending transients of this character are favorable in this connection. The alternator field current tends, by itself, to increase sufficiently to maintain constant magnetic linkages in the field circuit. So, the machine is not dependent, in the first moment of a shock, upon the exciter to increase the field. It does this itself, and the current tends to hold up for an appreciable time. This gives the exciter a chance. The period of oscilla-

7. "A Simplified Method of Analyzing Short-Circuit Problems" by R. E. Doherty, Trans. A. I. E. E., Vol. XLII, p. 841, 1923.

tion of a system is of the order of one second, which means that the peak of the first overshoot in power would usually occur in about a half second. It is in this swing that the *inherent* field current rise, or the transient reactance, saves the situation and gives the exciter voltage a chance to reach the proper level by the time conditions have settled. And as already pointed out, the standard design of exciter has, in many cases, sufficiently low time element to adequately meet this condition. Where special attention is required in making the exciter more responsive—perhaps in the large, slow speed exciters—there are a number of ways in which this might be accomplished. The most obvious, and perhaps the simplest is merely to decrease

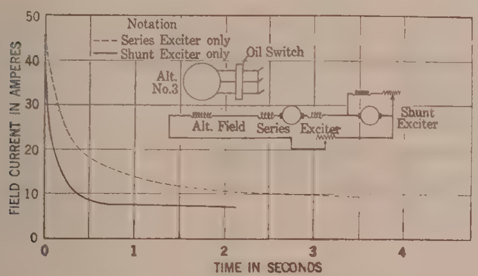

FIG. 9—EFFECT OF "SERIES EXCITER" IN LENGTHENING THE ALTERNATOR FIELD TRANSIENT

the duration of the transient in the same way the transient is shortened in any inductive circuit—by decreasing the value of the time constant L/R.

Such measures, if necessary, would apply to the larger exciters of low rotative speed—that is, machines of large volume. These have higher time constants because they have greater masses of copper and iron. To illustrate how these factors are related, Fig. 8 gives a number of points representing actual exciters over large ranges, showing the time constant plotted against kw./rev. per min., which, at given magnetic and current loadings, represents volume. It will be noted that these points lie well along the average curve. The exciters used in the tests fall at the points $b\ a$, $b'\ a'$ and $b''\ a''$.

Another and perhaps more efficient way of meeting the situation is to use the "series exciter" in the excitation circuit. This functions merely as a negative resistance, and thus neutralizes the effect of the ohmic resistance of the alternator field circuit. If it were not for the latter, the field flux of the alternator during a sudden swing in load would remain constant—that is, there would be no tendency for flux decay. So the alternator transient is lengthened by the extent to which the resistance is thus neutralized. This gives the shunt exciter a longer time in which to build up. Fig. 9 shows how the alternator field transient is lengthened by the series exciter. The total ohmic resistance was adjusted to the same value in either case.

Short Circuits. Short circuits are one of the most serious kinds of transients. This transient also calls into play all of the factors mentioned above. A three-phase short circuit on a branch of a system not only disturbs both the power and the magnetic balance of the generators, but also completely isolates the branch from the rest of the system until it is cleared. Loss of synchronism is usually expected in such cases.

A single-phase short circuit (which most of them are[8]) is not so serious, in that power flow is possible through the other phases past the point of short circuit. Whether the parts of the system break synchronism depends, among other things, upon the load at the time, the momentum of rotating masses, the duration of the short circuit, the electrical power transfer during the trouble, the restored voltage when the short circuit is cleared, and the amount of "induction motor" torque in the synchronous machines.

Long experience on existing systems is the most promising aspect of this question. Although now and then a case is reported where loss of synchronism follows a single-phase short circuit, it is rare where adequate relays with short time setting are used. This is a fact which cannot be overlooked in considering this important question. Calculations are usually made on the basis of conservative premises (as they should be) until basic data are complete; but even if such calculations indicate that loss of synchronism might occur oftener than good service could withstand, it must be remembered that experience rather indicates

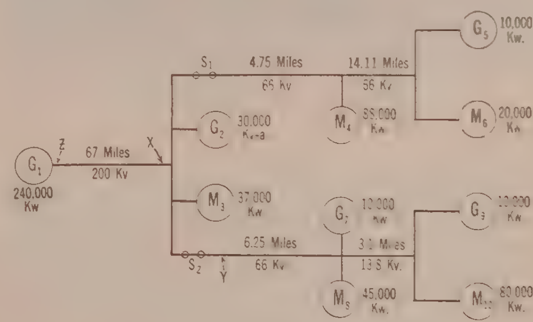

FIG. 10—TRANSMISSION NETWORK

the opposite. This is a problem on which sufficient detailed operating data have not been accumulated to afford adequate bench marks for calculation; and until this is accumulated, estimates must be no better than the premises on which they rest. Meantime, judgment, which is based on experience and such calculations as are possible, must be used in proposed undertakings.

An idea of the power oscillations following a single-phase short circuit at X on the system shown in Fig. 10 is given in Fig. 11. This is for a case in which the short circuit remains on the system, and the prime mover power is practically constant.

Many cases of transients similar to the cases referred

8. Particularly on high voltage systems in which the conductors are arranged horizontally.

to above, in which direct calculation is hopeless and step-by-step process is extremely difficult and often hopeless, can be effectively studied by Nickle's method, referred to above. In this, an equivalent electric circuit—involving no rotating apparatus—solves the equations, and the oscillograph plots the results.

With reference to all of the foregoing discussion of transients, while they may be much more difficult to solve than problems on steady state, methods of practical estimate and calculation are nevertheless available excepting for single-phase short circuits; but here it is less a question of method than of premises. Where direct mathematical methods fail, graphical methods can be used, as illustrated in the step-by-step processes devised by Bush and Booth.[9] Beyond this lies Nickle's equivalent circuit method.

Design

When the best estimates now available are made, it is found that, on the whole, the problem of increasing the

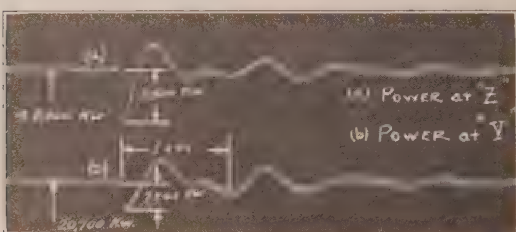

Fig. 11—Power Transient Following a Single-Phase Short Circuit at Point X on System Shown in Fig. 10

maximum power under all conditions of operation is principally one of designing apparatus and accessories that will give the greatest possible stability. It has been observed that this problem of stiffening the synchronous machines has been attacked along two lines: one relating to the design of the synchronous apparatus itself, the other to regulating schemes.

The problem of the designer of synchronous apparatus is to go to the limit in increasing the ratio of the field strength to armature strength, to the end that the armature reaction due to the load, shall have the least possible effect in distorting or decreasing the magnetic field. The object thus sought is usually referred to, whether properly or not, as low synchronous reactance. From the discussion of field excitation under *steady state*, it follows that it is desirable to design the synchronous machines so that they will require at all times and loads, as near as possible the field strength required by the maximum load; and to have this, in turn, as great as heating limits of the field will permit. Then, whatever the load, the machine is better prepared to take an additional load.

9. "Power System Transients," Bush and Booth, Journal A. I. E. E., p. 229, March 1925.

It is important to observe here that many generators for the usual commercial load of lagging power-factor are already designed to such a limit. These other measures for increasing the required field current are necessary in the present problem, because the power factor on long distance transmission lines is usually nearer unity than the ordinary commercial load, and therefore requires lower field excitation than the usual system load. In other words, what is thus attempted in design modification, is, in reality, only to increase the stability or stiffness of the synchronous machines under this special condition of operation, to that which it already possesses under the usual condition of lagging power factor operation.

The present problem, nevertheless, often demands more inherent stiffness than can be obtained by the above measures. This addition can be had only by increasing the size of the machine, which, of course, is both expensive and inefficient.

So the best that can be accomplished along the foregoing lines is hardly a satisfactory solution. It is an approach only, which, as it now appears, must be supplemented by effective regulating devices.

Regulation

This is the other general line of attack mentioned. The usual method of regulation is to automatically adjust the alternator field current by means of the vibrating type regulator operating on the exciter field, to hold the bus voltage as near as possible to a constant value. Referring to Fig. 3, the function of this regulator is to cause the generator to pass from one curve to another along the line $e\,e$. There are, of course, an infinite number of such curves, and under steady state the alternator is functioning on some particular one of them. The *extremely important* point here is that although at any load under steady state the voltage is the same, *i e.*, along the line $e\,e$, nevertheless the machine is not operating on $e\,e$ as an inherent characteristic, but on one of the family of curves shown. In other words, although the machine operates at an intersection of $e\,e$ and one of the curves, it is on the latter, not the former. That is, the rate at which the voltage changes with respect to a power change is, for the moment, the slope $\dfrac{d\,E}{d\,P}$ of the particular curve, and this determines the degree of stability. The less the slope, the greater the stability, and, in the limit $\dfrac{d\,E}{d\,P} = O$, there is the "infinite" generator. The slope of $e\,e$, of course, may be zero for any machine with a regulator, but that does not change the

inherent characteristic, on which the machine operates as illustrated in Fig. 3.

While it is not possible, in the nature of the case, to significantly change the slope of the characteristic by use of such a regulator, as explained later, it is possible to do it by other means of regulation. But before describing this, the general principle involved here which is not generally fully understood, will be further discussed.

It is one thing to compensate for the effect of a phenomenon after it has occurred, and quite another to compensate *while* it is occurring. In the former, the thing happens and is then corrected; in the latter, it, in effect, does not occur. To illustrate the first; load is thrown on an alternator the voltage of which is controlled by a vibrating-type regulator. The voltage drops, then the regulator contacts close, which in turn starts the exciter voltage to build up, ultimately providing the field current necessary to restore the voltage. The time involved may be short, but the foregoing is nevertheless the sequence of events. The drop occurs and then it is neutralized. An exciter with low time constant may hurry the phenomena along, but the time-constant, even if decreased, still exists and it is interposed in the above sequence.

On the other hand, consider for instance, the voltage drop in an inductive reactance of a feeder circuit. Add a series capacitive reactance of equal value. Then while the drop still exists across the reactance, it is, nevertheless, absolutely neutralized, at all instants, and at all loads, so far as the feeder circuit is concerned. The drop is compensated *as it occurs*, and the effect is the same as if it did not occur.

The difference between these two conceptions is the difference between what we have and what we should like to have in the principle of regulating alternators. If some one found such a scheme at once reliable and economically feasible for regulating alternators, there would be the equivalent of an "infinite" generator—one in which the change in voltage with change in load is zero, *i. e.*, $\frac{dE}{dP} = O$. And with apparatus so regulated at both ends of the line, the power limit of the line alone would have been attained. But such a scheme has not yet appeared in practical form.

To accomplish this in an alternator, two things are required. The armature reaction must be completely compensated by supplying opposing field ampere-turns of equal value in the proper space-phase and *at the time the armature reaction is occurring*. If this were accomplished it would be, in effect, as if there were no armature reaction.

The other point is that the leakage reactance must also be neutralized, which means that a voltage must be supplied which is in time-phase opposition to the voltage of the reactance. Theoretically, of course, this could be accomplished by series condensers of proper capacity, and this may sometime be practically feasible. Indeed, they may be used to neutralize the line reactance, as well.

To completely compensate for armature reaction, one is confronted by the difficulty both of applying the field ampere-turns in the right space-phase, and above all, of increasing it and decreasing it in exact conformity in time with the variations of armature reaction. However, while it is perhaps not to be expected that the ideal case will be realized practically, it is yet possible to partly compensate it by any scheme which will adjust the field current in rigid proportion to the armature current—which may be approximated by certain forms of self-excited machines.

But there appears to be a simpler way. Without expressing any assurance of practical application in the near future, it is noteworthy that a very substantial reduction in the effect of armature reaction has been actually obtained in a factory test by the use of the mercury-arc rectifier, as an adjunct in the excitation

Fig. 12—General View of the Test

system. Its function is merely to supply field current in rigid proportion to the armature current, thus compensating for the latter *at the time it occurs*. By the nature of the circuits, and the variation of power factor, the space phase could not, in this particular case, be what was required. Nevertheless, the reduction in effective armature reaction, as evidenced by increased maximum power at the same voltage, under steady state, was of the order of 50 per cent.

Let the significance of this be clearly understood. Two maximum power (steady-state) tests were made on a minature 250-mile line with a 225-kv-a. generator supplying a synchronous motor of the same size. Fig. 12 shows a general view of the test set-up. One test was made with an ordinary vibrating regulator controlling the voltage of each synchronous machine; the other, with the rectifier as an adjunct. In the first, the power was gradually brought up to 120 kw. at 2000 volts at both ends of the line, 7.0 amperes on the motor field, 7.5 amperes on the generator field. This was the maximum power the system could carry. A further increase caused it to break out of step. Then the rectifier scheme was installed. Similarly the load

was brought up to the same point—*i.e.*, 120 kw., 2000 volts, 7.0 amperes field current on the motor, 7.5 on the generators. This power was *not* maximum. It was further increased at the same voltage to 154 kw., or an increase of 28 per cent.

This test is mentioned merely to illustrate the principle discussed above. The point involved is the difference between the slope of a curve and the value of the function itself. Analogously, if moving bodies were being considered, the interest would be not in the speed alone but also in the acceleration. It is not the value of voltage, but the slope of the voltage-power curve, that indicates the degree of stability. If a system, controlled by vibrating regulators operating on the exciter is gradually loaded to imminent breakdown, the control can usually be taken over by hand and the same load held. In other words, although such regulators are highly effective in load transients in increasing the excitation as load is thrown on, they, nevertheless, do not significantly increase the steady state ultimate maximum power at normal voltage (p_3 in Fig. 3), over that corresponding to a fixed field current; and the reason is that, even with the regulator, the slope of the voltage power curve, in the first moment, is practically the same as if the regulator were not operating. And if it should be different during a sudden transient, it must ultimately return to steady state and thus to the slope corresponding to constant field.[10]

If this fact is not appreciated, it may be taken for granted, as frequently has been done before, that if the bus voltage is regulated, it may be assumed in calculations of maximum power that the voltage is *constant*. This assumption is justified only if $\frac{dE}{dP} = O$. It has even been proposed that by placing automatically regulated synchronous condensers along the line at given intervals, one may consider each of these sections as a unit, and that whatever power it is possible to transmit over one of them at the given voltage, can be transmitted, excepting losses, from one section to the other for a distance of, say, 1000 miles. Now this would be possible only with infinite generators and also infinite condensers—*i.e.*, such that the slope of the terminal voltage curve against reactive kv-a. supplied by the condenser is zero. To illustrate magnitudes, the maximum power of a 250-mile line at 220,000 volts, infinite bus at both ends, is about 225,000 kw.; of a 500-mile line, 130,000 kw. According to the proposal, with a condenser at the mid-point, it would be possible to transmit 225,000 kw., neglecting losses, over the entire 500 miles of line. Actually, a condenser at mid-point, of say 70,000-kv-a. capacity, would increase the maximum power only from 130,000 kw. to 156,000 kw. —not to 225,000 kw. This rather indicates what might be expected if the length were extended to 1000 miles.

Before concluding—regarding the foregoing discussion—it is well to mention again that consideration should not be confined to the cases of long distance straight-away transmission only. The problem in hand is one which, to a limited extent, relates also to power lines and networks of moderate distances, and the extent will undoubtedly become greater as the blocks of power to be transmitted continue to increase; or, indeed to tie connections of central station systems—to any, in fact, in which the power to be transmitted approaches the power limit of the system under the operating conditions. However, the problem involved in such systems, although more difficult to solve than those of single lines, is nevertheless the same; namely, to determine the power limits under various operating conditions, and to provide that these limits shall be as high as practically feasible.

What is the conclusion to be drawn from all of the foregoing discussion regarding synchronous machines? As to possible changes in design, the present indication is that no radical departure may be expected; that, at least so far as present proposals are concerned, reversion is made to the well established practises which have long since been followed in special cases where an increased stability or breakdown has been required: This is to to go to the limit in ratio of field strength to armature strength, and if that does not meet the required load, then get the remainder by merely increasing the size of the machine.

As to improvements by regulation, or more properly, compensation, it appears at this time that although there is possibly some hope for this in the future, the progress to date has been little more than the demonstration of the principle in actual test; but this affords sufficient incentive to actively pursue the investigation, when it is realized that for distances of transmission much above 300 miles the power limit with present equipment is such as to make these projects questionable from an economic standpoint, while, at the same time, the development of our resources will undoubtedly require the use of lines of this length in the near future.

Acknowledgments

The authors gratefully acknowledge the assistance of Messrs. C. A. Nickle and C. H. Linder in the preparation of data for this paper.

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The Radio Interference Problem and the Power Company

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Synopsis.—*In this paper, the author summarizes the growth in the number of complaints of radio interference, and outlines typical causes in the various fields of utilization of electricity with the aim of indicating the relative part chargeable to power companies. The radio industry itself, moveable or extraneous sources, signal lines and equipment, power lines themselves, connected power company equipment, connected commercial loads, household circuits and appliances, are discussed and location methods described, with mitigation measures which have been found effective.*

In its preparation, the writer has had at hand reports of member companies of the Pacific Coast Electrical Association (the Pacific Coast Section of the N. E. L. A.) as chairman of the Inductive Coordination Committee, and the results of tests conducted by the General Electric Company on various pieces of equipment. He has also had the benefit of committee discussion, both local and national, and correspondence and conferences with other men engaged in the common problem from coast to coast.

* * * * *

THE development and growth of the electrical-power industry, first with its localized plants in the vicinity of the load, later with its distant plants of large capacity, feeding many diversified loads over miles of transmission and distribution lines, are well known to members of the American Institute of Electric Engineers. During this development, the engineers were busy with the problems presented from day to day; how best to make the change from old to new types of apparatus; how best to serve a newly developed load; how best to care for swelling power demands and changes of load centers; ever adding to, and increasing the facilities to keep up with the urban. suburban and industrial growth of their territory,

While they were bent upon their own detailed tasks to keep up with this development, twice the cry has come from other industries; "You are interfering with our activities." The first was from the wire-communication interests, and for some years, inductive interference was studied in different sections of the United States, its general principles were determined, and working agreements, based on these principles and on mutual give-and-take policies, were entered into in many parts of the country. This added another group of problems for the engineer engaged in the task of increasing the kw-hr. consumption in his territory,—onerous they may appear to him, for they do not affect the satisfactory delivery of *his* product.

Again such a call has come; this time from the new field of radio broadcasting and reception. Again the disturbances complained of are from features which do not interfere with the delivery of kilowatt-hours. Some are even functional, the operation of equipment designed to do what it is doing and has been doing for many years is complained of by radio enthusiasts. Some are due to minor and temporary imperfections and occur but rarely on a given circuit. Many of both classes are due to equipment or circuits on the premises of the consumer, over which the distribution company has no control.

It was in 1923 when the electrical industry took formal notice of the radio interference problem by consigning its study to a subcommittee of the Inductive Coordination Committee of the National Electric Light Association. As just stated, the features said to cause disturbances did not interfere with the delivery of a power company's product. No direct economic law compelled the engineer to eliminate the radiation of a few micro-micro-watts here and there on the system. Only the social requirement of "live and let live" has caused him to take up the problem, determine the reasons for the anguish to the radio listener, and if due to faults on his lines, to correct them.

In the early months of the spread of radio popularity to its present phenomenal proportions, crystal sets and simple tube sets were general. It took a considerable

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Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

amount of radiated energy to "get through," and whenever it did, the power company knew it as soon as the radio listener. But with the increase in the use of multi-tube sets, amplifying many thousand fold the radiations picked up by an antenna and making it possible to hear very distant stations, there came also additional susceptibility to emanations from nearer at at hand, even though not intended.

At first static was accredited with practically all interference. Then somebody said that power companies were responsible. Guided beyond the truth by over-zealous editorial writers, radio listeners began to charge everything disagreeable to the power companies, up to and including the aforementioned "static."

But knowledge is increasing, and whereas a year or more ago only 10 per cent of the complaints made to a certain power company were really chargeable to their equipment, about 40 per cent is the present ratio. This is due in a large measure to more definite identification on the part of the radio listener and those who attempt to aid him in the solution of his troubles; and furthermore, to the wider dissemination of radio receiving sets, which is responsible for a larger number of complaints for a single cause.

Classes of Radio Interference

Broadly, man-made interference with radio reception may be roughly divided into two classes, that from high frequency continuous waves, and that from damped waves.

In the first class the causes are chiefly chargeable to the radio industry itself. Among them may be listed radiating receivers; high power oscillators; broad-band emission and harmonics, generally due to improper operation and crowding; variation from assigned frequency of transmitting stations, either intentional or otherwise; key thumps from improperly designed transmitters in code stations; spacing waves from arc transmitters with their numerous harmonics and parasitic radiations; use of unnecessarily high power for the existing radio conditions at the moment and careless testing; superpower broadcasting stations unwisely located. Harmonics from carrier current transmitters have been found responsible for some interference in this class, some of these having sufficient energy to get through the transformers and travel considerable distances. This is the only cause in this class attributable in part to light and power companies, and but few of the companies using carrier systems have been charged with interference from this source. Modulated, continuous wave signals are also objectionable.

The second class is far more prolific in its effects and includes many more types of equipment as trouble makers. The highly damped waves are the worst offenders. A large portion of this class is also chargeable to the radio field.

Spark-transmitting sets, with rather high decrements, are still in use. Ship-to-ship and ship-to-shore code signals break through on the finest programs. We welcome our fleet to our local harbors but such an occasion is not an unmixed blessing. The number of sets with this type of equipment is being reduced gradually, and it is hoped that others will be improved by reducing their decrements to less objectionable values. The only justifiable uses for highly damped waves or broad-band emission in general, is in calling and distress signals.

Movable or Extraneous Sources

The spark plugs from automobiles and stationary gas or gasoline engines give out a small amount of radio frequency energy. This does not interfere with the less sensitive receivers unless in close proximity to them. To a sensitive set adjusted to high amplification for the reception of distant or weak signals, considerable interference may be caused. Suitable shielding should obviate trouble from this source.

Signal Lines and Equipment

Telephone and telegraph lines themselves do not give rise to interference impulses, as they carry but little energy. If such impulses are induced in them or delivered to them, they may radiate disturbing waves over a large area. However, the telephone service wires within the house have delivered radiations of many kinds to an antenna lead placed inadvertently close to them.

Telephone ringers have been common sources of trouble to the radio listener. The ringing generator may be supplied either from a direct current source or from a 60-cycle service. The output may be either a pulsating direct current for polarized bells or an alternating current for common bells. In either case the current wave has a steep front. The pole changer consists of a vibrator carrying two or more contact members which close a battery circuit upon the line or upon one winding of an induction coil and send a pulsating or alternating current over the line.

An a-c. converter is sometimes used to supply higher voltage of direct current to the pole changer. The supply of 60 cycles or other frequency may then be converted into any ringing frequency desired.

The arcing at the contacts causes the radio interference due to this apparatus, as there is superimposed on the ringing current, a radio frequency current modulated with the frequency of interruption of the pole changer.

Watchman's alarm, fire alarm and bank protection systems operating on the contact make-and-break principle, are known to radiate waves within the broadcasting bands.

Interference from Power Lines

Transmission and distribution lines have been so often blamed for radio interference that it is well to consider carefully all possible reasons for the emission

of disturbing waves from these circuits. Transmission lines, having relatively great length and high voltage, and carrying considerable energy, may become very serious offenders if they are at fault.

Functional Disturbances

Normally, their emanations of electromagnetic waves are of low frequency in the audible range. A 60-cycle tone is little more than a rattle; the triple harmonic or a 180-cycle wave gives the characteristic hum of electrical machinery and apparatus on the 60-cycle system. This forms the greater part of the residual current or voltage always present in a three-phase system. Higher harmonics may be present due to generator wave form, more or less accentuated or subdued by the characteristics of the line, but none of these can be detected very far on either side.

The same can be said of lines at distribution voltages. Trolley lines and feeders, however, give off emanations at radio frequency due to the constantly occurring arcs at rolling and sliding contacts. These impulses are given off from all points of the trolley system as one comprehensive antenna. They are often carried by induction to distribution and communication lines and from them, picked up by the aerial of the radio listener. The characteristic trolley noise has been traced from ground current, due to poor bonding, which was carried by telephone-cable sheathing and which induced similar current in the overhead wires.

Disturbances due to Faults

Insulators. Defective insulators are sometimes sources of disturbance on transmission lines. The arc formed is due to leakage along the core, cracked porcelain, or a low resistance path of dust or moisture or both. The high-voltage arc generates a highly damped disturbance which travels a considerable distance and is radiated to an appreciable extent. If an insulator is simply leaking down the core, the wave length is very short, and the disturbance will not travel more than a span or two, but if there is an external discharge, the whole line is excited, there is a long wave-length fundamental and the disturbance may be carried for miles by the line itself and by other lines which pick it up by induction.

On distribution systems, insulators do not give trouble unless actually defective or extremely dirty. The safety factor of insulators is somewhat higher for these voltages and the low voltage does not establish an arc very readily.

Poor Contacts. Poor contacts on switches connected to the line cause radio frequency wave generation from the slight arcing which takes place at these locations. These waves are radiated from the wires connected to the switch as far as they extend in both directions, but in general do not get through a transformer winding. Imperfect connections at splices or taps may also lead to arcing of the same nature, and disturbing radiations are given out over a large area.

Leakage to Ground—Trees and Guys

Leakage to ground may vary from an actual short circuit from wire to ground with a clinging arc, to the small occasional tree grounds and contact with grounded guy wires. The first is usually of short duration and ceases when the protective relays open the circuit, which takes place quite soon except in rare cases where arcs occur so far from the station that the current values are under the settings on the overload relays.

Wires blowing against trees, particularly in wet weather, give rise to slight arcs over the high resistance paths thus provided. In somewhat the same category is the swinging of power wires against guys, which produces similar effects. In general, however, these troubles are confined to distribution lines, as such conditions on high-voltage transmission lines will, in most cases, operate the relays although they may repeatedly recur in the case of distribution lines without affecting the delivery of power.

Tie wires, when loose or when insulated wire was used in conformity with local regulations have sometimes caused radio trouble.

Connected Power Company Equipment

Some types of apparatus used and useful in rendering service to the consumer, but belonging to the power company, is sometimes responsible for radio disturbances which are carried out over the lines.

Transformers. We often hear the assertion that "leaky transformers" are causing radio interference. For some reason this is quite a popular term in the radio world, but of course the power man knows that there is no leak possible in the transformation process. If close enough, an ordinary audio frequency amplifier will pick up the core hum of a transformer by straight induction, but this is functional and continuous.

Defects in transformers and their connections may be instrumental in causing disturbances. Cracked bushings have the same effect as cracked insulators anywhere on the line. Poor connections of leads give rise to small arcs just as do poor connections at taps, switch points or plug cut-outs. In a few cases, incipient failure of insulation has made itself manifest by slight discharges to the core or case. If these are at the extremities of the winding, the impulses may travel along the line and be radiated therefrom. Poor contacts in the ground lead from the case have been found to cause serious radio interference. Neutral grounds with imperfect contacts or in which the surrounding earth has dried out, have given rise to similar trouble.

Generators and Motors. The sparking at the commutators of generators and motors produces interference which may affect radio receivers located near by or be picked up by other lines and reradiated

by them. This is responsible for some of the radiations from the trolley systems as already noted. The effects of bad arcing at the brushes of a rotary converter will easily pass through the low impedance winding of the converter and travel as far as the transformer. If the converter is connected directly to the line, the disturbance will travel over the entire line to the feeding-in transformers.

Lightning Arresters. The electrolytic lightning arrester is an old offender of the wire-communication industry, and is also found to give trouble in the radio field. Its action depends upon the critical voltage which will overcome the resistance of the film between electrolyte and plate. This dissolves gradually so that the resistance is lessened and it becomes necessary to "charge" the arrester periodically by subjecting it to line voltage, the current flow building up the resistance of the film to its former value. For many years in most sections of the country, this charging has been done in the early morning hours when it may be accomplished with the least disturbance to communication lines, and few radio listeners will be affected. The arrester is normally in series with a horn gap, so proportioned that it will discharge only in case of rises in voltage such as those due to lightning or surges. Such discharges are functional and so infrequent that they hardly enter the problem.

Oxide film, auto-valve and series-gap lightning arresters are also disturbing only when discharging such excess voltages. If the gaps are too close on the latter type, continual sparking may occur.

Street Lighting Equipment. Contrary to a general belief, present day arc lights do not produce appreciable radio interference. The radio listener is fortunate that he did not have the privilege of trying for DX in the days of the open d-c. arc and Thompson ball armature arc generator with its three-section, widely-spaced commutator. The enclosed arc is quite steady in its nature, and beyond a slight click in the receiver when the carbons come together and separate, which takes place a very few times during an entire night, interference is negligible. Even "lamp jumping," caused by defects in globes or operating mechanism, cannot be detected far from the lamp. Poor connections to the arc lamp may cause radio frequency waves, just as they do to any electrical apparatus.

Series incandescent lighting circuits have been at fault in a number of cases, but in normal operation they do not cause trouble. From the nature of the circuit—a single wire extending for a long distance in the form of a large horizontal loop—it will radiate a disturbance over a large area when any connected apparatus is at fault. The causes of the radio frequency waves are, in general, poor contacts in the sockets, faulty film cut-outs, discharges from live parts to metal parts connected to ground, and broken or cracked porcelain.

Mercury arc-rectifiers sometimes give rise to radio frequency waves, modulated to the frequency of the supply line, which are sent out over the d-c. arc circuit. This is very seldom the case with a new tube, but is an indication of approaching failure. The immediate cause is called "fading" and is due to a lag in the time of starting of one or both arcs in the tube. If allowed to continue the fading gets so bad that "pumping," or complete loss of arc in one anode, will take place and the tube will either arc across or puncture one anode seal.

Connected Commercial Loads

A number of pieces of apparatus in commercial use generate radio frequency waves which are radiated from the apparatus itself and from the supply circuits.

X-Ray machines give considerable annoyance to the more sensitive receiving sets in the vicinity during the time they are in operation. Fortunately this is for a few seconds, only, at any one time and there are intervals between the periods of use. Further, they are used mainly in business hours and are quiet at night.

Violet ray apparatus normally produces rather severe radio interference. This being operated by means of a vibrator, induction coil and vacuum tube in connection with a tuned circuit, gives rise to high-frequency impulses which are radiated from the supply line throughout its length.

Smoke and Dust Precipitators. The Cottrell precipitation plant makes use of the static field from high-voltage direct current. This may be produced either by a step-up transformer and mechanical rectifier or by a kenotron set in which the alternating current is rectified by a mercury arc. The kenotron rectifier, when in normal condition, creates no interference, but small static discharges are continuously being made in the treater box. Mechanical rectifiers add to this by severe sparking at the contact points. Radiations are then emitted from the entire lead from the rectifier to the treater box.

Apparatus for Battery Charging. Mercury arc rectifiers have already been treated under *Power Company Equipment.* Those used on commercial circuits are usually small in size and any radiations produced go no further than the secondary windings of the transformer on the distribution line.

Tungar rectifiers do not generate radio frequency waves in normal operation.

Vibrating rectifiers produce slight interference to radio reception but this is usually of a low period,—that of the contact arm. They do not interfere with sets which are reasonably selective if the desired signals are strong.

Electric elevators of the direct-current class usually interfere more or less with radio reception in the buildings in which they are located. Two types of interference are noticeable—a click in the receivers when the contactors open or close, and noise when the motor is operated, varying from core hum when it is running smoothly to a roaring sound when the commutator is

sparking badly. The waves are radiated from the wires feeding the motor as well as from the arcing contacts themselves, but as a rule, the lengths unshielded by conduit are not great. For this reason there is little difference in the effects of the d-c. elevators and the a-c. feed, d-c. operation elevators of recent years.

Electric Furnaces. Furnaces of the arc type generate radio frequency waves, particularly when the conditions are changing, as when the furnace charge is being melted down. After conditions are steady, very little interference is caused. Very little interference gets through the step-down transformers feeding the electrodes to be radiated from the supply line. Furnaces of the resistance type do not generate disturbing waves except when connections are faulty.

Other industrial uses of electrical power give rise to high-frequency waves, but as the large works are usually at a distance from residential sections, there are few listeners affected. At a large insulator factory, the regular and necessary flashover tests on insulators caused considerable disturbance until the test room was thoroughly shielded.

House Circuits and Household Appliances

The residence consumer is, in general, the one most interested in the radio interference problem. A large share of his radio troubles arises on his own premises. Quite frequently power companies have gone to considerable trouble and expense in running down a radio complaint, only to find the cause in the set itself or in the wiring or appliances of the complainant or his neighbor, in no way the responsibility of the power company to maintain.

Loose contacts at entrance switch, fuse plug, wall switch, or even lamp socket have often made DX reception very difficult and unpleasant. The switching on and off of lights or loads produces clicks in the receiver, but pitted contacts may cause severe interference to be radiated all along the secondary system because of the small arcing which takes place.

Electric flatirons do not normally develop interference, but the amount of power they consume renders an arc rather persistent if contact is poor. Their manner of use makes them subject to recurring arcs if the contact parts are loose, and this causes unpleasant interference.

Motor Driven Appliances. Washing machines, electric fans, vacuum sweepers, dish-washing machines, and the smaller classes of rotating apparatus, are usually driven by series commutator motors. These are not subject to careful inspection while in use, and there is commonly more or less sparking at the commutator, which causes interference which may be picked up for several blocks along the secondary lines.

Heating Pads. Heating pads with thermostatic control have been found occasionally to be the cause of rather widespread interference from arcing at the thermostat points. The secondary circuit is excited by the ragged sparks, and in some cases enough energy goes through the transformer to excite the primary circuit, causing it to oscillate at its natural period. The heating pad is a particularly vexatious offender, as its time of use so generally coincides with the time of the radio programs. Pads of some manufacture are better than others in this respect, the design of the thermostat being the controlling feature.

General

In general, radio interference is caused by electric arcing of irregular nature, and static sparks. These may be localized, as in dust precipitators, elevator motors, etc.; or the disturbance may travel for considerable distances if the sparks are in a part of an extended circuit. There is also the possibility of the circuit being excited to its natural period, thus increasing the radiations of a definite wave-length and certain favored harmonics.

Disturbances are usually confined to the circuits on which the sparks occur, although at times sufficient energy gets through the transformer to excite the primary circuit to resonance. Also a disturbance may be picked up inductively from another circuit and radiated over a wide area so that it is difficult to associate it with the actual cause.

Location Methods

There are many points involved in the technique of locating causes of radio interference. Independent workers in the various sections of the country have struggled with the problem as it increased in acuteness, and have acquired experience which made their later work far less time-consuming.

It generally saves time if the power company has a set at least as sensitive as the complainant's set which may be connected in its place. If there is no interference on the company's set, it is apparent at once that that of the complainant is at fault, and unless the fault is quite evident to the tester he may be referred to his radio dealer or fellow amateurs, or aided further depending upon the policy of the power company.

An early step in the detection of causes would appear to be a classification of the noises produced by various sources of disturbing waves. The hum, the click, the rattle, buzz, "squirrel noise," hammering, crash and roar are each produced by a limited number of causes, and their association will at once focus attention on a particular group. Determination of the nature of the wave, whether it is audio- or long or short wave radio-frequency, will materially assist in the identification.

If the type of noise is one which may originate in the house circuit, opening the entrance switch will generally determine the cause, though it should be borne in mind that the disturbance may come in by way of the serv-

ice. Ingenuity in reasoning out the location of the fault is readily acquired by the tester.

Outside causes of interference are located best by a rather sensitive but substantial portable set and suitable transportation. A directional loop is of considerable aid in most cases. However, account should be taken of the fact that a loop will point to the immediate source of the waves which it receives, and this may be the line only while the fault may be at a distant part of the line. For this reason triangulation from two positions is not always reliable. If three or more observations indicate a common point, more credence may be given to the indications. An actual arc or faulty insulator may sometimes be located in this manner by a sensitive set. Often the loop will point with great persistence to poles with vertical risers on them. This is, no doubt, the reason transformers are so often blamed unjustly.

The characteristics of a loop as direction finder should be understood. Improvement in its directional properties has been made by connecting condensers across the terminals of the loop so that the two positions of minimum lie approximately in the same straight line.

A more trustworthy use of the loop is by testing for relative noise at different locations with a horizontal loop. Having located a line which is radiating interference, it may be followed to a position of maximum noise, where close inspection will usually disclose the fault. An audibility meter is an aid in this process, as it gives quantitative measurements by which the distance to the fault may be approximated, and its location found more readily than by ear alone.

In San Jose, California, the power company is experimenting with a method of locating faults by means of a well insulated condenser, one terminal of which may be hung on the individual wires of a distribution line and the other terminal connected to a receiving set. The wire on which the fault exists can then be determined by comparative noise, and traced in the usual manner, with a loop, to the location of the fault. If this cannot be detected by the eye, further use of the condenser will determine just what splice or contact is involved. For example, at a faulty tap, a loud indication may be heard on the tap line and on the main line toward the source of power, but on the main line beyond the tap, where the current is not affected by the poor contact, much less noise will be heard. Similarly faulty insulators can be indicated by touching the pins with the condenser.

Mitigation Measures

The effectiveness of methods for eliminating radio interference depends upon whether or not the generation of the disturbing waves is functional or due to a fault.

The radio industry is working toward the elimination of the causes for which it is responsible. This is in the direction of greater control hoped for over the radio-operator, both commercial and amateur, a gradual lessening in the number of spark-transmitting stations, the education of the radio layman in the correct use of his receiver, discouragement of the use of reradiating receivers and eventually requiring changes in the circuit or shielding of offending oscillators.

The communication interests have developed means for draining off radio-frequency impulses from their circuits quite successfully. This is readily accomplished for two reasons; first, the station equipment is the most usual source of interference, and secondly, the voltages used are low and no great risks are taken with operation by the insertion of supplementary apparatus. The different types of pole-changers and ringers may require different treatment, but judicious use of filters, choke-coils and shielding, has proven quite effective. These means have not been applied to communication lines which have picked up the interfering waves by induction.

The audio-frequency hum of a power line is functional and no remedial measures are practicable. If it is necessary to have an antenna near such a line, it should be at right angles to it for minimum interference.

Similiarly, the radio-frequency interference from trolley lines is a normal accompaniment of their operation. So many pieces of equipment on different parts of the circuit produce it—rolling contacts at trolley wheels and rails, sparking at brushes and controller fingers or contactors—that no method of elimination is applicable.

When the interference is due to faults in equipment, the remedy is obvious. Dirty or defective insulators should be cleaned or replaced, and contacts at taps and switch points made satisfactory. It is sometimes an advantage to the power company to have a good argument for tree-trimming.

Transformers, if found defective, usually have to be replaced and sent to the repair shop. Generator and motor operation can be bettered by care in adjusting the brushes and by keeping the commutators true. Some cases have been helped by placing two condensers in series across the terminals and grounding the middle connection.

Lightning arresters of the electrolytic type are usually charged at hours which will not interfere with broadcasting programs, but the Government or commercial code stations, operating on a 24-hour schedule, will still be subject to interruption of messages.

Arc lights, which cause interference by lamp jumping, should have the broken or cracked globes replaced. If this does not check the interference, the flexible leads to the electrodes should be replaced. In series incandescent circuits, defective sockets and automatic cut-outs should be weeded out.

When mercury arc rectifiers are at fault from "fading," one company recommends adding static protectors to the anodes; another remedy is washing and boiling the tube in a steam bath. Allowing the tube to stand in the sunlight will slowly adjust the vacuum and remove the conditions which cause fading.

It is possible to drain off the interfering waves from this equipment by adding a simple filter in the outgoing leads.

Violet ray apparatus has been successfully drained of radio-frequency waves by connecting two one-microfarad condensers in series across the leads and grounding the middle connection.

Interference from smoke and dust precipitators may be eliminated by shielding the rectifier and the lead-wire to the stack. In cases where the supply leads carry and radiate the disturbance, it has been successfully drained by placing a suitable condenser between each line and ground.

Similarly drains, filters, and shielding, may be applied to some other types of commercial apparatus with favorable results. Careful study should be made of the situation and the nature of the disturbing waves determined, after which decision can be made as to what remedial measures, if any, give promise of success.

The same considerations apply to household circuits and appliances. Faulty wiring, house switches and connected apparatus can be corrected; the commutators of small motors of vacuum cleaners, washing machines, etc., can be smoothed to advantage, but some pieces of apparatus with thermostatic control offer no ready means of correction. The manufacturers are at work developing thermostats which give sufficient separation of contact points to prevent arcing, and it is probable that in time the troubles from heating pads will disappear.

Where the wiring is placed in iron conduit, the house circuit is well shielded and the disturbing radiations do not reach the line. If the service only is in conduit, little, if any, of the radio waves reach the line, though they may be radiated from the house-wiring as a branched antenna.

Suggestions have been made that a resonant circuit be developed which would drain away any radio-frequency current which might be imposed upon a line, without interfering with operation, as has been done in the case of communication circuits. While this can be done and has been done on the leads to offending apparatus, it is not applicable to the line. Every piece of equipment, every insulator, is an element of weakness in the line, and the tendency is to lessen, rather than increase, their number. If a fault should arise where such apparatus is located, it would be effective without question, but if it arose anywhere else, the offending waves would be attracted and increased rather than suppressed. For proper supervision such apparatus should be installed at a substation. As few causes of radio interference arise at a substation compared to those which arise on a line, the interference would be aggravated rather than helped.

In general, when a cause of radio-frequency emanations is located, the application of known principles of electric circuits can be applied to the elimination or mitigation of the disturbing waves. The economics of the situation, the practicability of the corrective measures, their effect on the major purpose of the apparatus, the question of by whom the burden is to be borne, the policies of the interests concerned,—all enter into the much vexed problem. Due consideration of all these features will determine the proper solution to be applied.

Distribution to Supply Increasing Load Densities in Residential Areas

BY M. T. CRAWFORD[1]

Fellow, A. I. E. E.

INTRODUCTION

FOR many years residence service was merely a matter of a few hundred watts lighting-load per house, with a poor load factor. The electric iron then came into use, followed by many other socket appliances, considerably increasing the consumption with only a moderate increase in the demand.

Within the last few years, conditions have been favorable, in many places, for electric cooking in the home, and where the electric service companies have encouraged such use there has been a rapid increase in the number of electric ranges connected to their distribution lines. The residence which formerly required a few hundred watts became individually a load of around eight kw. or more. More recently, water heaters have been added to range installations, with a tendency in some places to go from the smaller units of 500 to 1000 watts for continuous operation to sizes around 3.5 kw. for intermittent operation with thermostatic or hand control.

In cities where rates for residence service slide with increased use, down to a very low figure per kw-hr., there has been some attempt to use electricity for house heating, although under most conditions it is economically unsound.

Distribution systems, generally, have been able to satisfactorily take on a reasonable amount of this load increase, but in localities where ranges are being connected by the thousands, it has been necessary to con-

1. Of the Puget Sound Power & Light Co., Seattle, Wash.

Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., September 15-19, 1925.

sider radical changes in distribution practise, to economically meet the new conditions. In this paper, an outline is given of the plans and construction of the Puget Sound Power and Light Company designed to meet the new conditions along residential distribution lines in and around Seattle, in anticipation of a discussion which will bring out information of value.

Load Characteristics and Density

Among the principal factors which determine the design of any distribution system are the characteristics and requirements of the load and the density of load per unit area. The necessary requirements of the load having been met, maximum economy is always essential.

Residence service demands a reasonably high service continuity and good regulation. Voltage regulation has been planned to come within a normal maximum range, approximately two per cent each way from the lamp standard of 120 volts.

The load density is a variable factor which is increasing. Starting with a newly opened suburban addition with only a few houses to the block, very light load densities are at first obtained; but these increase during a development period up to the time when all lots are improved. Then follows a period of partial apartment-house or "bungalow-court" apartment construction when conditions are favorable. The distribution system under discussion here is designed for service conditions between these limits, and does not consider rural lines, where a primary voltage of 6 kv. to 13 kv. is used, or solidly built apartment, hotel or commercial areas.

Tests and surveys have been made to determine the actual feeder demands to be anticipated from various classes of residence loads in combination, as the diversity factor is quite high on the appliance load. Exact data on the diversity factor of a large number of range and water heater installations in this territory are being collected by the Electric Range Committee of the National Electric Light Association by means of distant dial totalizing meter equipment, but only preliminary data are available at this date. From this data and other tests under local conditions, the diversified feeder demand has been estimated to average of 500 watts per residence having only lighting and small appliances, 1250 watts per residence having a range also, and 1600 watts per residence having also a large water heater.

An average city block has been taken to include 0.004 square mile which will include from sixteen to twenty fair sized lots and the necessary street area. To be anticipated for use shortly, an average maximum load density of 25 kw. per block or 6250 kw. per sq. mi. has been designed for an average consideration of seventeen houses per block, estimating for five with range and water heater, eight with range alone, and four with only lighting and small appliances, plus a thirty range apartment house every six blocks. Much greater load densities are already obtained in certain locations, close in areas, well built up with range-equipped apartments, given special consideration, more or less underground construction being involved.

Principles of Design

It was planned to construct a distribution system which could, without reconstruction, be added to as the load density increases. With this in view a maximum load density has been designed according to the requirement reasonable to expect at present, and the lines are so laid out that at first when the load density is light only a portion need be built.

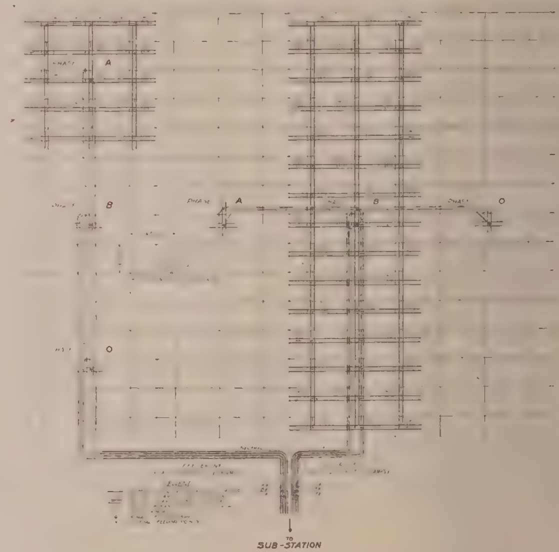

Fig. 1—Diagrammatic Outline of Principles Employed on Overhead Distribution System

Complete development shown in upper corner on phase *A* of feeder No. 1 Partial development for lighter loads shown on center on phase *B* of feeder No. 2. This form of construction makes it possible to start with secondary network only, and adequately serve all load-density increases by adding primary network, transformers and feeders with no reconstruction work.

The general intention is to cover the entire residence area with a grid form of service network of uniform conductor size, irrespective of load density. Increases in load density can then be taken care of by running out additional feeder capacity and tapping this grid at more frequent intervals.

The standard lamp voltage is 120 volts and a maximum service regulation of two per cent above and below standard is normal. A nominal primary distribution voltage of 4500/2600 volts, four-wire, three-phase, star grounded is employed, supplying single-phase service by means of three-phase feeders which are balanced as nearly as practicable by dividing the service area into three uniform load sections for each feeder.

Distribution System Ultimate Construction

The secondary bus or street mains consist of three No. 4 wires, of uniform size at all points, operated on a

single-phase Edison, three-wire basis with neutral grounded. If practicable, this bus is built longitudinally along the streets or alleys, and at intervals of approximately every two blocks or about 800 feet, cross-ties are installed over cross streets between the longitudinal runs. In this manner a solid grid network is constructed.

For the ultimate load density, a maximum size of secondary grid of about five by six or thirty blocks is standard. Insulating circuit breakers are placed in the bus around the edge of this grid to separate it from adjoining networks, except that no circuit breakers are placed in the neutral conductors.

Fig. 2—Typical Construction on Lightly Loaded Grid

Showing one-wire primary and three-wire secondary. Vacant pin position on crossarms for future feeders, polyphase branch lines, street lighting circuits, operating telephone and miscellaneous

A single-phase, primary grid of one No. 4, weatherproof wire is installed parallel to the secondary bus as to both location and area, Standard 10:1 transformers are installed between the primary and secondary grids at such locations as the load demands, up to an average of one 25 kw. unit in the middle of each block. The secondary bus neutral is used also as a primary return from the grounded side of the transformer to the feeding point in the center of the grid.

For load densities at present anticipated, primary feeders are of standard size No. 4/0 copper, from the substation. Four wires are taken out for a three-phase feeder and three 30-block areas supplied therefrom, chosen as far as possible so as to be of average uniform distance from the substation. When the three-phase primary feeder reaches a central point in this load area, each of the three-phase wires branch off and tap into the center of the No. 4 primary grid, covering one of the 30-block areas.

Branches from the neutral feeder follow each single-phase primary branch and tap the neutral grid at the same point where the primary grid is tapped. Additional taps may be made from the neutral feeder wire to various points in the neutral grid when necessary as determined by neutral current tests. These are made periodically and at the same time the transformer loads are measured. Not less than one No. 4/0 neutral is installed along the route of each feeder from the substation to all feeding points but where several feeders take the same route one neutral conductor only may be installed for their combined use.

The accompanying diagram shows the plan in outline. For the average block size and uniform load distribution careful calculations were made of network currents and voltage gradients, to check the wire and equipment sizes and spacings adopted as standard.

In actual practise, block sizes and shapes vary considerably, and load densities vary from block to block, but these conditions are successfully met by adjusting the size and location of transformers.

Development Period Construction

The above design is for the presently anticipated ultimate load density where a 300-ampere feeder will be loaded in a thirty-block area. Starting with very light load densities, feeders may be operated at 200 amperes and one feeder may be used to supply a much larger area. Three of the thirty-block areas referred to, which are ultimately to be used to load the three phases of a three-phase feeder, are combined into one ninety-block area, and the circuit breakers omitted from the primary and secondary grids so as to make a one-grid network over the entire area. The single-phase No. 4/0 branch feeders, ultimately to supply separate grids of smaller extent, are spliced together and taken to the station as one single-phase feeder. In extremely light load densities, two ninety-block areas are served by one No. 4/0 single-phase feeder, but their primary and secondary grids are kept separated by circuit breakers.

Fig. 3—Construction in Heavier Load Density Areas

Showing 13-kv. transmission, feeders and polyphase leads along with primary and secondary grids; also other utility circuits, railway, telephone, etc.

A ninety-block area is considered a maximum which it is good practise to operate on one secondary grid for reasons of service continuity.

Voltage Control

The principle employed in the voltage control and regulation is to compensate, by the substation regulator, for all drops up to the feeding point in the grid, plus the drop in distribution transformers, plus the drop in the customers' service, these items being considered fairly uniform in proportion to the load for all points of service. The voltage drop in the primary grid from the feeding point to the transformer plus the voltage drop in the secondary grid from the transformer to the service pole varies at different service points and the sum of these two is kept within a maximum range of five volts in order to give two per cent service regulation.

Fig. 4—Typical Distribution Substation for Best Class Service Full Automatic

With underground line entrance and feeder getaway. 13-kv./4-kv. transformers installed in open bays in rear of substation

Fig. 5—Distributing Substation in District where Future Development will be Largely Light Manufacturing with some High-Class Residence Service

Full automatic, with 13-kv./4-kv. transformation equipment, out of doors

Conditions sometimes arise where the voltage control is distributed by the connection of large range-equipped apartments at certain points of the grid. In all cases of this kind, ample transformer capacity is installed on the service pole for the heavy load, involved the elimination of the secondary grid drop. Calculations and tests are made, and if it is found that the voltage drop in the primary grid alone exceeds 20 volts, a branch feeder of suitable size is installed from the normal feeding point to the low spot on the primary grid, establishing a supplementary feeding point.

Polyphase Power Service

Large blocks of industrial power are supplied from 13-kv. loop feeders. Lighter industrial loads are supplied by separate three-phase, 4500-volt power feeders which are carried when necessary and are not provided with automatic voltage regulation. In cases where small polyphase loads are to be served in residence areas where there is not enough such business to justify the construction of a power feeder, it is permissible to bring in taps from the adjoining primary grids on other phases, to supply a small polyphase transformer bank. Very light polyphase loads are cared for by one secondary phase from the lighting bus.

Fig. 6—Temporary 13-Kv./4-Kv. Transformer Installation

Used in new outlying residential districts for up to three 200-kw. transformers. Used until load development warrants buying property and building substation

Substation and Supply Facilities

Distributing substations of the best modern types are constructed for service in the well-developed residential areas, in order to be able to give service of high class reliability and regulation. Automatic reclosing and selective switching features with spare apparatus and duplicate sources of supply are provided, together with voltage regulation, on all lighting feeders. All substations are supplied from a 13-kv. secondary transmission network covering the city, which is fed from three independent receiving stations, each with its own supply, from the 55-kv. transmission network leading from the hydroelectric generating stations.

These substations are constructed at intervals of approximately three miles, giving a nine square mile

area and a maximum feeding distance of two miles to the farthest corner of this area. Except in the downtown, underground district, none of the present substations have their entire service area developed to a high load density, although well developed in certain portions of the area. A maximum of 12,000 kw. per substation has been sufficient capacity to plan for, so far, but additional land has been provided so that future extensions may be made. A capacity of 50,000 kw. will be required when the average load densities reach 25 kw. per 0.004 sq. mi. block. Heavy industrial power is not considered in these figures, as 13-kv. loop feeders are used for such service.

In outlying suburban areas, a temporary pole-top transforming installation is initiated during the development period, which may be from five to fifteen years, until the load warrants purchase of land and construction of a substation. Two independent 13-kv. supply lines are tapped and in some cases automatic operation is provided for the 13-kv. selector switches, actuated on low voltage of normal supply. Outdoor feeder regulators are installed for voltage control, and where several feeders are run out, automatic reclosing equipment is installed on crossarm-mounted, 4500-volt feeder switches.

Discussion

This system has been under construction for the past few years, replacing a two-phase, four-wire distribution. However, the secondary grid networks have been in use for many years, and, to a limited extent, so has also the primary grid principle. Almost all cases of secondary trouble burn clear or, at most, blow a nearby transformer fuse, although primary trouble frequently results in a circuit outage. With the grid form of network, a single troubleman can cut out a defective section and resume service at once on the entire feeder.

Our experience has indicated that the cascading of transformer fuses during transformer or secondary trouble, seldom occurs on lightly loaded network busses covering extensive areas. The small size of conductor used on the secondary bus will tend to prevent it even under the 25-kw-per-block conditions. The system is so planned, however, that if this should become a problem and service continuity require it, network protectors or power directional secondary switches could be installed on transformers supplemented by an interlacing of primary feeders. This method of service protection has been given extended application on our underground distribution system.

The use of a strictly radial primary feeder system would effect a saving in linear feet of primary lead, but it would be necessary to taper off the wire size in order to avoid excessive voltage gradient between feeding point and outer edge of service area with heavy load densities. The added cost of the larger wire, together with the cost of pulling out and pulling in wire to keep up with the load growth, will about offset the cost of the added linear feet of primary in the grid form of feeder. The use of a secondary network effects great economy in transformers, and where good construction is employed it has been our experience that service has been improved.

A higher primary distribution voltage was given consideration and it was found that it would effect considerable saving in feeder copper under heavy load density conditions, but would add to the cost of transformers and line construction. High voltages are principally of value to cover distance, and it was felt that as much load would ultimately be obtained within the economic radius of 4500 volts as should be intrusted to one distributing substation, considering the importance of the service. In the rural and country home districts, the 13-kv. to 4-kv. substation is eliminated, or replaced by pole-top transformer installations, and a large area supplied by 13-kv. feeders from a substation having a 13-kv. voltage regulator on the bus. This practise is possible in such districts due to the less exacting service requirements, and to the absence of heavy railway and fluctuating industrial power loads on the 13-kv. network in such territory. High-voltage, pole-line construction in built-up city areas is considerably more expensive than the 4-kv. construction which permits of joint pole arrangements and space economy.

Summarized, the advantages of the system outlined are believed to be:

1. Construction economy under conditions of light-load density at first followed by rapid growth in more or less unforeseen localities.
2. Ability to meet the more exacting requirements of voltage regulation and service reliability demanded by increase in domestic use.

LONDON'S FRANCHISE QUESTION NEAR SETTLEMENT

The electricity commissioners, after five years of study, have at last worked out a tentative plan for the allocation of electric service franchise rights in Greater London. While the arrangement proposed is recognized as not being in accordance with the best commercial engineering practise, it is the result of a compromise on all sides and will secure at least more efficient operating conditions than exist today. Under the proposal, London and the Home Counties will be served by fewer individual undertakings than at present, there being an association of interests on the part of private companies rather than on the part of the existing municipal systems, and an attempt will be made to coordinate operation by a so-called joint electricity authority.

By the adoption of the plan, the spread of electric service in London will, undoubtedly, be facilitated and probably there will be a tendency toward greater uniformity in voltage and frequency. Furthermore, in view of the fact that the systems will then operate with a greater degree of security and under definite franchise conditions for a period of years to come, they will be more free financially to modernize their systems and to make extensions.

On the Nature of Corona Loss

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and

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Introduction

If a high voltage is applied between two electrodes, experience shows that in any given case there is a limiting voltage below which no loss occurs, a permanent current flows only if the voltage is an alternating one and is then a purely charging current. Above this voltage loss appears, accompanied by the familiar phenomenon of corona; a permanent current flows even in the case of continuous potential, showing that the air space between the electrodes becomes a conducting part of the circuit.

If E is the applied voltage and Q the quantity of electricity which has passed in the circuit, then with alternating potentials the relation between E and Q is represented in rectangular coordinates by a closed curve whose area is a measure of energy per cycle. The $E-Q$ relation is therefore of prime importance in the study of corona loss.

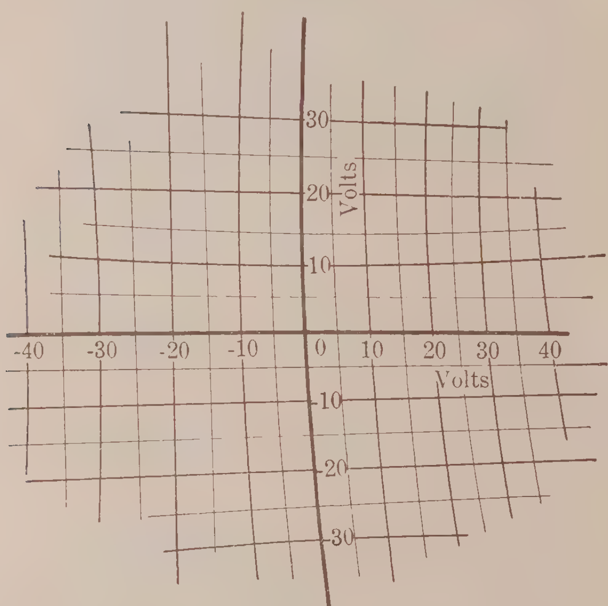

Fig. 1

A number of such $E-Q$ diagrams of corona loss have been taken, and the results are presented in the first part of the paper. They lead to certain conclusions regarding the nature of corona loss discussed in the second part of the paper.

Part I

The $E-Q$ diagrams were obtained by means of the cathode-ray cyclograph. In this instrument a stream of electrons emitted by a hot filament of a vacuum tube is directed along the axis of the tube by means of a strong electric field. The inside of the opposite end of the tube is covered with fluorescent material which becomes luminous at the spot where the electrons strike it. Along its path, this stream passes between two consecutive pairs of parallel metal plates arranged at right angles to one another.

If the relation of two variables is desired, voltages proportional to these variables at every instant are applied between the corresponding pairs of plates. The electric fields set up by these voltages deflect the ray and cause it to describe a luminous curve on the fluorescent screen. For further detail, the reader is referred to an article by J. B. Johnson, *Bell System Tech. Jour.*, Vol. I, p. 142, Nov., 1922.

On account of the weakness and non-actinic qualities of the light produced by the luminous spot, it was necessary to make all observations visually and record them by tracing on a piece of tracing cloth held against the end of the tube by means of a special fixture. In order to calibrate the tube, two sets of readings were made using alternating voltages in one pair of deflectors and known values of direct current voltage in the other pair. From this test a set of coordinates shown in Fig. 1 was plotted, by means of which any $E-Q$ card can be corrected for distortion and replotted in rectangular coordinates. All areas, whether replotted or not, were corrected for distortion.

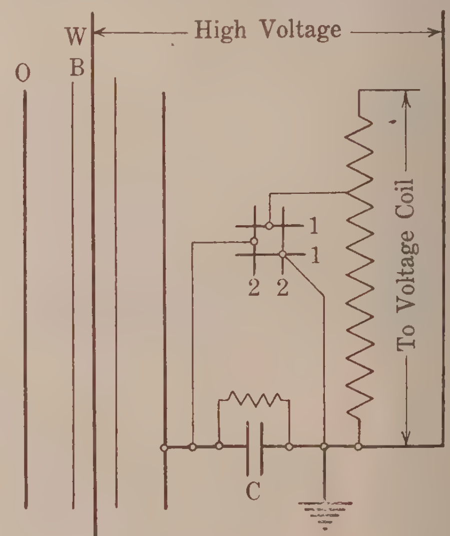

Fig. 2

A typical connection diagram is shown in Fig. 2; W and O are the electrodes (in this case a wire and a cylinder); B is an electrically isolated cylinder whose

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Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., September 15-19, 1925.

purpose will be explained later. 1—1 are deflectors connected across an adjustable portion of a resistance placed across the voltage coil of the high voltage transformer. These deflectors give a deflection proportional to the applied voltage, E. Deflections proportional to Q are obtained by connecting the other pair of deflectors,

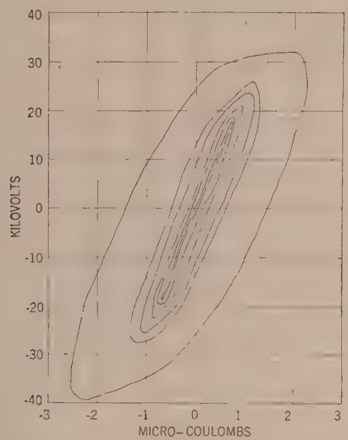

FIG. 3—BARRIER EXPERIMENT—60 CYCLES

0.034-in. diam. wire in 16-in. diam cylinder
No barrier

2—2, across a large capacitance C, connected in series with the outer cylinder. These deflectors are also shunted by a resistance of the order of a megohm. Without this precaution the plate not connected to the

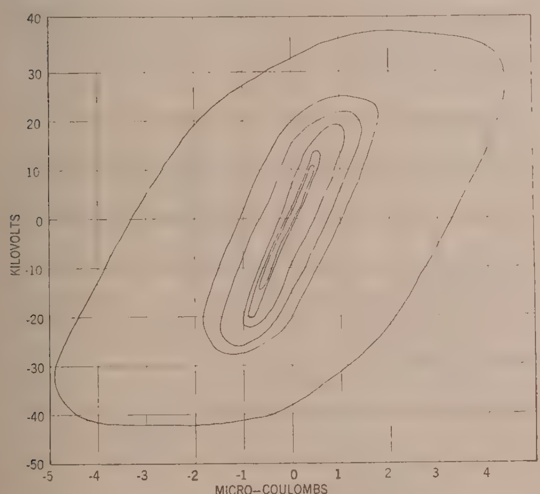

FIG. 4 BARRIER EXPERIMENT—10.5 CYCLES

0.034-in. diam. wire in 16-in. diam. cylinder
No barrier

anode would collect a charge and the spot would drift. Since the action of corona over positive and negative crests is unsymmetrical, there is a tendency for the capacitance, C, to accumulate a unidirectional charge, which is also drained off by this shunting resistance. The diagram itself gives the voltage across this resistance so that the current in it can be calculated and the diagram corrected for it. The effect of this resistance was found to be negligibly small.

Most of the tests were made with the classical arrangement of a wire along the axis of a cylinder. The connection between corona loss and the conduction of electric charges through the air space was studied by placing in the path of the charges, insulated barriers, B (Fig. 2), in the form of concentric cylinders of different diameters. The walls of these barriers were always thin so as not to modify the original field, and it was then of no consequence whether they were made of conducting or insulating materials.

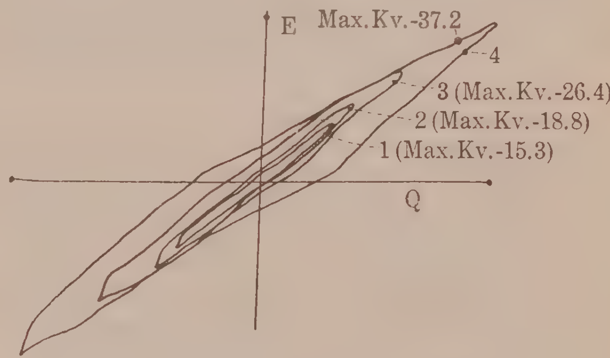

FIG. 5—BARRIER EXPERIMENT—60 CYCLES

0.034-in. diam. wire and 16-in. (mesh) cylinder
Barrier metal cylinder 1⅛ in. in diam.

In all cases the wire was of copper 0.034 in. diameter, and the outer cylinder O was formed of ½ in. mesh wire screen 16 in. in diameter. Figs. 3, 4, 5, 6 and 7 show some of the diagrams obtained with this wire and cylinder arrangement.

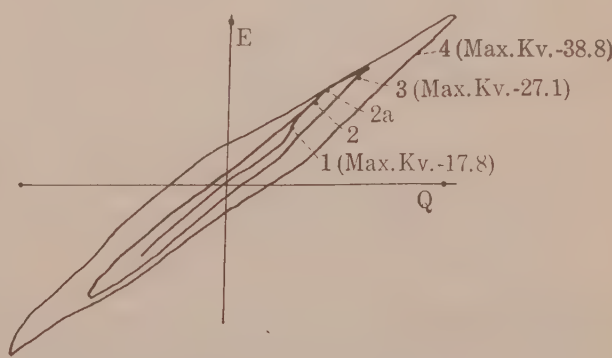

FIG. 6—BARRIER EXPERIMENT—60 CYCLES

0.034-in. diam. wire in 16-in. diam. (mesh) cylinder
Barrier glass cylinder 1⅛ in. diam.

In Figs. 3 and 4, the original cards (taken with no barrier at 60 and 10.5 cycles respectively) were replotted in order to reduce them to a common scale.

Figs. 5, 6 and 7, taken at 60 cycles and all at the same scale, are reproduced without any change; barriers

were of 1 1/8 in. diameter metal tube, 1 1/8 in. diameter glass tube and 11 in. diameter metal tube, respectively.

Fig. 8 shows $E-Q$ areas (in joules) for the same maximum voltage (28.5 kv.) as a function of barrier diameters.

Fig. 9 is the reproduction of a card taken at 60 cycles on a 230-ft., single-phase line composed of No. 20 copper conductors spaced 36 in. apart. Figs. 10, 11 and 12 show cards taken on the same line at 60, 120 and 10.5 cycles respectively, replotted to the same scale.

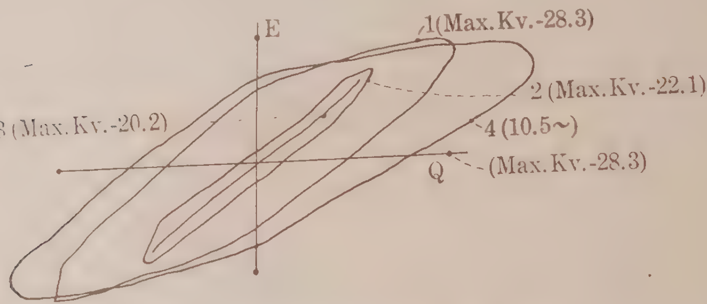

Fig. 7—Barrier Experiment—60 Cycles

0.034 in. diam. wire in 16-in. diam. (mesh) cylinder
Barrier metal tube 11 in. diam.

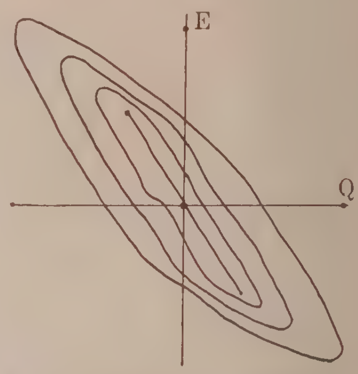

Fig. 9 —Outdoor Line —60 Cycles

No. 20 copper, spaced 36 in., 230 ft. long

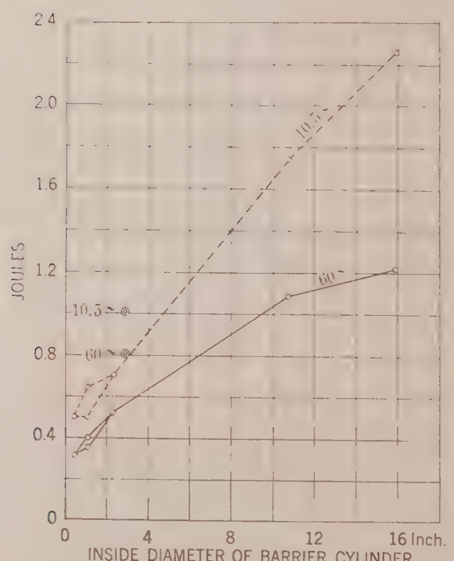

Fig. 8—E-Q Curves as a Function of Barrier Diameters

0.034 in. diam. wire in 16-in. diam. (mesh) cylinder
Maximum kv. = 28.5

Part II

The general characteristics of the $E-Q$ curves suggest the following explanation of corona loss:[3]

When the electric field acting on a free electron exceeds a certain critial value, the velocity acquired by the electron becomes so great that when it collides with an atom of the air it dislodges other electrons from this atom; that is, ionizes the air; and if this field is exceeded throughout a certain definite minimum distance from the conductor (critical corona striking distance), visible corona appears.

The liberated ions of opposite sign to that of the wire move towards the wire and can be assumed to reach it instantly, the zone of active ionization surrounding the wire being always very narrow; the ions of the same sign as the wire move away from it, towards the outer cylinder. To move these ions, energy must be expended by the source of e. m. f. creating the field. *Corona loss is this energy*, regardless of the place where it is expended, near the surface of the wire, or on the boundary of the zone of active ionization, or midway between the electrodes; the manifestations of corona perceptible to our senses—light, sound, heat—are caused simply by further transformations of the kinetic energy imparted to the ions by the electric field, and depend on the place

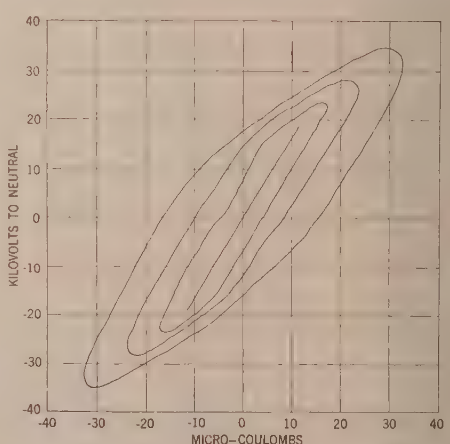

Fig. 10—Outdoor Line—60 Cycles

No. 20 copper, spaced 36 in., 230 ft. long

3. See paper entitled "The Hysteresis Character of Corona Formation" by Prof. Ryan and Prof. Henline, Journal A. I. E. E., p. 825, Sept. 1924.

and the mode of these transformations; within the zone of ionization, the energy is mostly spent in the invisible process of ionization by collison; if the impact of an ion against an atom of the air is strong enough to disturb the equilibrium between the nucleus and an electron of the atom, but not sufficiently strong to separate them permanently, the electron returns to its original position by a sort of vibratory motion, giving up energy acquired from the colliding ion in the form of light. Outside of the ionizing zone, the path of an ion is marked by a series of collisions with the atoms of the air; at each collision a part or the whole of the kinetic energy of the ion is transferred to the atom; if the ion strikes a solid electrode, its kinetic energy is converted into heat. If the applied e. m. f. is alternating, the ions in the air space move as alternately positive and negative waves; an outgoing wave meets a return wave of opposite sign; in the ensuing process of recombination, the energy of the ions is radiated in the form of light.

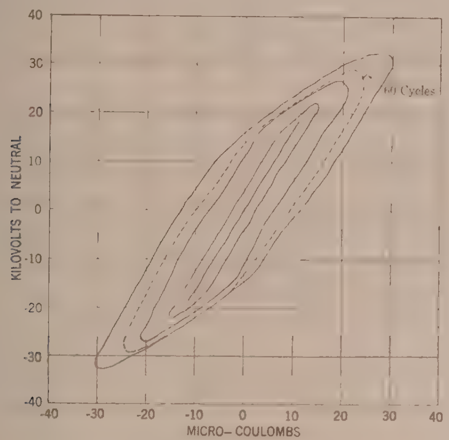

FIG. 11—OUTDOOR LINE—120 CYCLES
No. 20 copper, spaced 36 in., 230 ft. long

For simplicity, it will be assumed that positive and negative corona phenomena are identical.

In the corona caused by a continuous potential, the unidirectional flow of ions across the air space between the electrodes constitutes a true current in the circuit containing the applied e. m. f. The power expended in corona originates in the cooperation of this corona current with the applied e. m. f. In the corona excited by an alternating potential, a wave of ions may not cross the distance between the electrodes before the reversal of the field; in this case the to-and-fro motion of the waves of ions in the air space sets up a motion of electric charges induced by electrostatic induction in the circuit connecting the electrodes and containing the applied e. m. f.; the action of this e. m. f. on these induced charges corresponds to the corona energy loss.

If a barrier is placed infinitely close to the outer cylinder, we have an exact equivalent of the system of a wire in a cylinder, without any barrier: if there is no barrier, an ionic charge crossing the air space and arriving at the outer cylinder will neutralize an equal and opposite charge on this cylinder; if a barrier cylinder, infinitely close to the outer cylinder, is present, these two charges will remain separate but infinitely close to one another; in both cases their combined external action will be zero. For the sake of generality, it is convenient to assume that a barrier cylinder is always present.

As before mentioned, the action of corona is to release into the space a charge of ions; an equal charge of opposite sign goes to the wire. By analogy with the vacuum tube terminology, the former charge will be called "space charge;" at any given moment it may be located entirely in the air, or entirely on the barrier, or be distributed in the air and on the barrier. Let $-Q$ be the charge on the outer cylinder and q = charge on the wire; the total charge of the system being zero, the space charge x is given by the relation

$$x + q - Q = 0$$

hence $x = Q - q$. Let E be the e. m. f. applied between the wire and the outer cylinder; with the barrier cylinder placed between the wire and outer cylinder, the charge $-Q$ can reach the latter only through the circuit containing E; hence this charge on the outer cylinder is the same as the charge Q in the E-Q diagram.

The amount of space charge is controlled mainly by two factors: the variation—in time—of the field near the wire, and the initial ionization (number of free ions

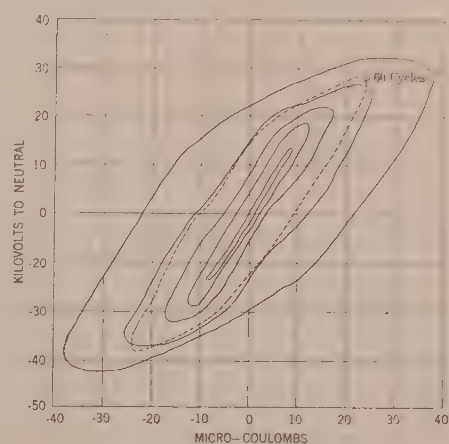

FIG. 12—OUTDOOR LINE—10.5 CYCLES
No. 20 copper, spaced 36 in., 230 ft. long

at the moment when the field reaches the ionizing value); the field here means the resultant of the field due to the applied e. m. f. and the field set up by the space charge.

It will be assumed[4] that, as a limiting influence, the second factor is negligible relative to the first, *i. e.*, that the antecedent ionization is sufficient to cause an instant and unlimited ionization by collision, unless checked by the drop of the field caused by the reaction of the space charge; in other words, as long as corona

4. See Footnote No. 3.

lasts, the action of the space charge is to maintain the same distribution of the field in the zone of active ionization as that which exists at the moment when corona starts for the first time. This hypothesis means that during the existence of corona, the charge on the wire must remain constant and equal to the charge which it has when corona first starts; if the initial critical corona voltage is E_0, and the capacity of the wire to the outer

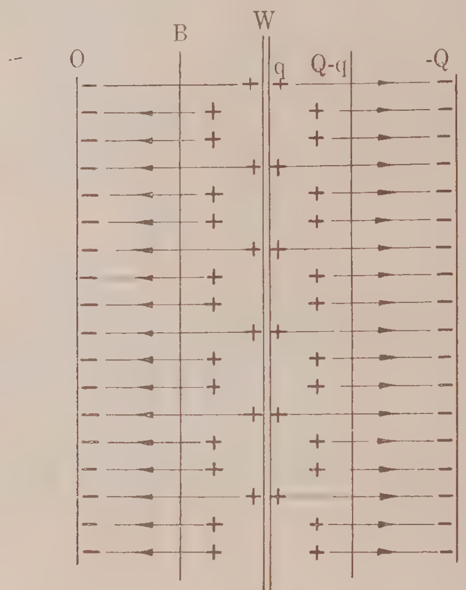

FIG. 13

cylinder is C, then this charge is $Q_0 = C\,E_0$; therefore,

$$q = Q_0 \tag{1}$$

Fig. 13 shows the distribution of charges. The charge q on the wire, with an equal and opposite charge $-q$ on the outer cylinder set up a potential difference q/C; the space charge $Q - q$ and an equal and opposite charge on the outer cylinder set up a potential difference E'; the sum of these potential differences must at all times be equal to the applied voltage E; therefore,

$$q/C + E' = E \tag{2}$$

Equation (**1**) applies only during the portion of the cycle when corona exists; equation (**2**) holds good throughout the cycle.

For the purpose of experimental verification of the theory it is convenient to study the simple case when the distance between the wire and the barrier is so small that the interval of time required by the ions to reach the barrier is negligible relative to the period of the supply voltage. The entire space charge is then on the barrier; if the capacity of the condenser consisting of the barrier and the outer cylinder be denoted by C', the potential difference E' due to the space charge $Q - q$ is $(Q - q)/C'$, so that equation (**2**) becomes

$$q/C + (Q - q)/C' = E \tag{2a}$$

The equation of the E-Q curve when corona exists is obtained by substituting $q = Q_0 = C\,E_0$ [equation (**1**)] into equation (**2a**); this gives

$$E = Q/C' + E_0\,(1 - C/C') \tag{3}$$

This is a straight line, 1—1, Fig. 14, of slope $1/C'$, which passes through the point C of initial corona (*i. e.*, starting for the first time, without any space charge).

When the voltage reaches its maximum value at M and begins to decrease, corona immediately stops. For, beyond M, the continuation of corona would mean that in equation (**2**), q/C would remain constant by equation (**1**), while E' would increase on account of the increasing space charge, the net result being an increase, not a decrease, of the applied e. m. f. E.

After corona stops, the space charge remains constant, *i. e.*, $Q - q =$ (constant); the equation of the $E-Q$ curve for this part of the cycle is obtained by substituting $q = Q -$ (constant) in equation (**2a**); this gives

$$E = Q/C - (1/C - 1/C') \times \text{(constant)}$$

This curve is a straight line $M\,N$ of slope $1/C$, *i. e.*, of the same slope as the precorona line $O\,C$ of the condenser formed by the wire and the outer cylinder.

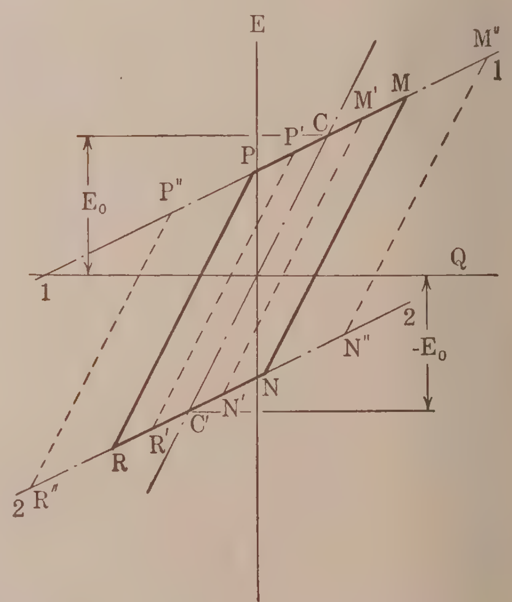

FIG. 14

By reason of symmetry, corona of the opposite sign will follow the straight line 2—2, parallel and symmetrical to the line 1—1. This line passes through the point C' symmetrical to C and corresponding to the critical voltage $- E_0$; but corona begins earlier, at N, because the space charge on the barrier now assists the applied voltage E in producing the ionizing gradient (field).

If the maximum of the voltage corresponds to the

points, M' or M'', the loops, $M' N' R' P'$ and $M'' N'' R'' P''$, may have very different appearance.

Let E_m be the maximum value of the applied voltage; the area of the $E - Q$ loop is $4\, E_0\, (E_m - E_o)\, (C' - C)$.

The characteristic features of the loop of Fig. 14 are well in evidence in Figs. 5 and 6, where the diameter of the barrier cylinder is small enough to justify the assumption of the instantaneous transfer of ions from the wire to the barrier, yet large enough to minimize the effects of various irregularities, such as eccentric location of the wire relative to the cylinder, vibration of the wire, dirt on its surface, etc.

The simplified diagram is independent from the frequency; it is also not affected by the wave shape of E so long as the latter has no multiple peaks.

If it is attempted to extend this construction to the case where the barrier coincides with the outer cylinder, the lines 1—1 and 2—2 become horizontal, and the loop extends to infinity. This absurd result is due to fact that so long as the charge on the wire is constant, the increment of the space charge is equal and opposite that of the outer cylinder, and, being infinitely close to the latter, completely neutralizes it so that there is nothing to prevent an unlimited amount of corona discharge. In this case the finite velocity of the space charge cannot be ignored.

Suppose, now, that the velocity of ions is not infinite; then a space charge may exist not only on the barrier but in the space between it and the wire. If the field were unmodified by the presence of the space charge it would be easy to predetermine the motion of an ion; the field at a distance x from the axis of the wire is

$$g_x = \frac{E}{x \log \frac{R}{r}}$$

where R and r are radii of outer cylinder and wire. Therefore, the velocity being proportional to the field, the distance x is determined from the equation

$$\frac{d\,x}{d\,t} = \frac{a\,E}{x \log \frac{R}{r}}.$$

where a is a constant and E is a function of time t. This equation, integrated for the case where $E = E_m \cos \omega\, t$, gives

$$\frac{x^2}{2} - \frac{x_o^2}{2} = \frac{a}{\log \frac{R}{r}} \int_{t_o}^{t} E\,d\,t$$

$$= \frac{a\,E_m}{\omega \log \frac{R}{r}} \; (\sin \omega\, t - \sin \omega\, t_0)$$

where $x_0 = x$ at the boundary of zone of ionization from which the ion starts and t_0 = time at which it starts. This relation is shown in Fig. 15 for a 0.034-in. diameter wire in a 11-in. diameter cylinder. The abscissas E_0/E_m give the ratios between the critical corona voltage E_0 and the maximum applied voltage E_m. The ordinates show the maximum travel of ions: the upper branch, for the ions discharged as soon as the voltage reaches the value E_0, increasing, and corona begins; the lower branch, for the ions discharged when the voltage passes the value E_0, decreasing and the corona is on the point of stopping.

However, the study of the experimental E—Q curves shows that the field is profoundly modified by the space charge; the analytical treatment of this case with alternating potentials is a difficult problem; but it is easy to explain all the peculiarities of the experimental curves, as affected by the voltage, frequency, etc. Since these peculiar features are of no importance except as a proof of the validity of the theory, only a few of them will be analyzed below.

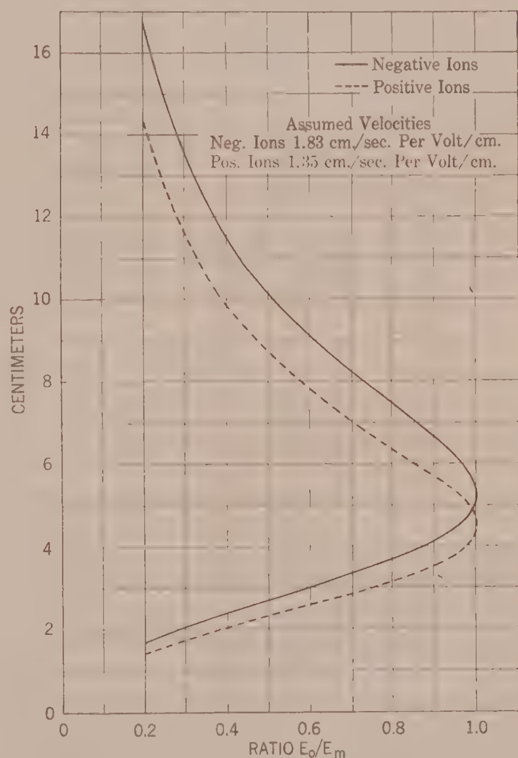

Fig. 15—Travel of Ions in a Radial Field

(0.034-in. diam. wire in an 11-in. diam. cylinder) E_o = critical corona voltage = 16.4 kv. at 60 cycles (maximum)

Experiment gives a loop such as shown in Fig. 16. Assume that at M, where the voltage is maximum, the polarities are as shown in Fig. 13. Corona stops at the point A, where Q passes through the maximum. For, if x denotes the space charge, we have $Q = x + q$; as long as corona exists, q is constant and x increases; therefore Q increases; as soon as corona stops, x remains constant and q decreases; therefore, Q decreases.

The applied voltage at A, where corona stops, is necessarily higher than the critical value E_0, because the action of the space charge is to oppose the field at

the wire due to the applied voltage. After corona stops, the space charge $x = Q - q$ remains constant, *i. e.*, $d\,Q = d\,q$, and the slope of the $E-Q$ curve results from equation (2):

$$\frac{d\,E}{d\,Q} = \frac{1}{C} + \frac{d\,E'}{d\,Q}$$

At first the potential difference E' decreases because the space charge approaches the outer cylinder. Be-

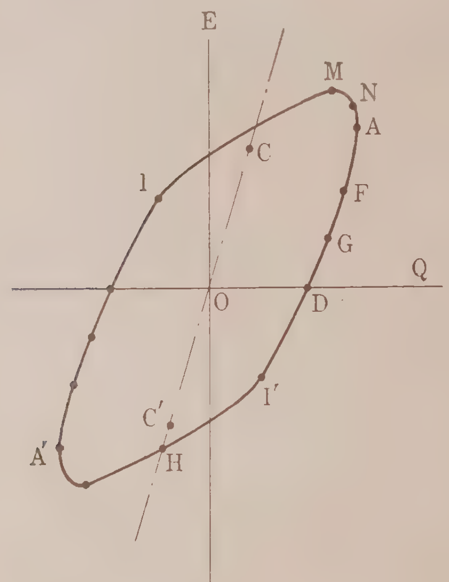

Fig. 16

yond M the decrease of E is small while that of E' is finite; there must be a compensating increase of Q; at A the decrease of E is just equal to that of E'; beyond A, E decreases faster than E', as shown by decreasing Q. At A, $q = Q_0$, and is positive; at D, where $E = O$, q is already negative, as otherwise the sum of q/C and E' could not be zero; therefore, there exists a point F where $q = O$; at this point the field near the wire reverses; with the increasing negative q the region of reversed field increases, gradually overtakes the ions of the space charge and causes them to flow back to the wire; the rate of decrease of E' diminishes and soon E' begins to increase; since the space charge now cooperates with the applied e. m. f. in setting up the field near the wire, the ionizing gradient is soon reached and corona discharge begins at I' before E reaches the critical value E_0. At the point G, where E' ceases to decrease and begins to increase, $d\,E' = O$ and the slope is $1/C$; at this point the tangent is parallel to the precorona $E-Q$ line $O\,C$.

At I' the corona discharge suddenly releases into the air space a negative charge, while an equal positive charge goes to the wire; the negative ions meet and discharge the residual positive space charge so that the net result is as if this residual positive charge were suddenly transferred to the wire; the variation of E' caused by this sudden transfer must be balanced by an equally sudden variation of Q; this explains the more or less abrupt change of the slope of the $E-Q$ curve at I'. Beyond I' the new charge gradually discharges and supersedes in the air space the residual space charge; at A' the negative space charge is maximum; corona stops, as at A, and so on, throughout the cycle.

If the frequency is low, the ions of the space charge will have time to reach the barrier; at very low frequencies the amount of space charge in the air will be small relative to the charge accumulated on the barrier, and conditions of Fig. 14 will be approximated; at very high frequencies the ions will have no time to move from the wire beyond the corona-striking distance; the effect will be as if the barrier were close to the wire; the $E-Q$ loop will again be as in Fig. 14, but this time with a very small area. As at all frequencies the area

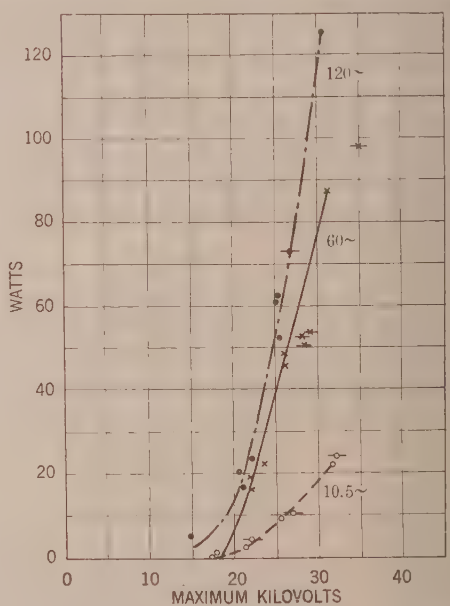

Fig. 17—Corona Loss—High-Voltage Wattmeter Readings and Cyclograms Short Outdoor, Single-Phase Transmission Line

No. 20 copper conductor, spaced 36 in., 230 ft. long

Wattmeter Readings		Cyclograms	
o	10.5 cycles	— o —	10.5 cycles
×	60 "	— × —	60 "
.	120 "	— . —	120 "

is controlled by the same factors, the amount and the extent of travel of the space charge, we can say; from very high frequencies to very low ones the area increases from nearly zero to a maximum corresponding to the sharp-cornered loop whose construction was given in connection with Fig. 14.

In the practical case for high frequencies, because of the formation of a very open brush pattern wherein the brushes shield the intervening spaces preventing all corona, the ions returning to the conductor are few compared with the ions of both signs remaining in the brush-streamers, the space charge becomes negligible and the phenomenon changes over to one of ordinary

conduction. In air, at common pressures and temperature, laboratory studies to date indicate that the space-charge type of corona formation disappears at a frequency of about 5000 cycles.[5]

With the same outer cylinder, the greater the diameter of the barrier the greater is the extent of the travel; therefore, the greater the area of the loop; but only up to a certain limit: if the diameter of the barrier becomes so great that the number of ions reaching it begins to decrease, its influence on the area becomes less and less pronounced, and vanishes altogether when ions cannot reach it at all.

The curves of Fig. 8 confirm these statements: the low frequency curve lies above the high frequency curve; when the diameter of the barrier increases, the area increases, but at a gradually diminishing rate. Points denoted by ⊙ refer to a test made with the barrier cylinder formed of ¼-in. mesh wire screen; their displacement from the respective curves shows distinctly that the screen, like the grid in a vacuum tube, is not a perfect barrier in the path of the ions. Double points for 1⅛ in. diameter are taken from two tests.

The arrangement of a wire in a cylinder was used on account of its theoretical and experimental simplicity, but the foregoing conclusions are not specific to this arrangement. In all cases of corona there is a space charge whose action is always of the same general character. An $E - Q$ loop is bounded by two distinct kinds of curves, each of a more or less constant slope, corresponding to a continuous variation of physical elements, but with a sort of discontinuity and an abrupt change of slope at the junction points, due to the sudden appearance and disappearance of corona. Curves of Figs. 9, 10, 11 and 12 show these general characteristics; in Fig. 17 the loss computed on the basis of Figs. 10, 11 and 12 is compared with the loss directly measured with the high voltage wattmeter, and the agreement is very satisfactory.

5. Eugene D'Hooghe, "The Influence of Frequency on Corona Discharges." Standford University Thesis, June, 1922.

Present State of Transmission and Distribution Developments

By Committee on Power Transmission and Distribution[1]

THIS Committee submits the following report on the progress made during the past year in the field of Power Transmission and Distribution. In accordance with the plan proposed, a number of subjects are offered at the end of the report suitable for topical discussion at the Annual Convention.

In high-tension transmission, the year has been notable for the first normal operation of the two long-distance 220-kv. lines in California and the concrete proof of the entire feasibility of lines of this sort. The importance of this fact is difficult to exaggerate. Already several other 220-kv. lines are projected; one now going under construction. The physical construction of these lines will soon be pretty well standardized and no longer a matter of serious controversy.

While the evidence as to the feasibility of 220-kv. lines is clear and convincing, there remains much uncertainty as to the limitations of the capacity of such lines when of great length. Much quiet work has been done, since the forceful presentation at the Philadelphia A. I. E. E. meeting last year of the dependence of very long lines on the rigid maintenance of line voltage and the weakness of commercial synchronous condensers for this purpose. The prospect is bright for better operation than would have been expected. At present, the work is largely in the hands of the designers of the various sorts of apparatus involved in line-voltage support and regulation.

It may be well to mention that the explanation of the many mysterious insulator flashovers on high-voltage lines in central California, which have baffled investigations for some time, has been established as the presence of large birds roosting on the towers and guard rings. This difficulty has now been, or soon will be, practically eliminated.

An old problem has come into unusual prominence in certain places, viz., the more or less severe vibration of highly stressed conductors, due to wind action causing the formation of standing waves and endangering the cable strands. This subject is being worked upon.

Little progress has been made in the discussion of the various aspects of the subject of flux control in very high-tension insulator strings. The well-known guard ring seems to be holding its position.

Much field work has been done on corona losses. It is to be expected in the measurement of these losses on long lines, subject to varying voltage and climatic conditions along their length, and sometimes of varying

1. Annual Report of Committee on Power Transmission and Distribution.

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Presented at the Annual Convention of the A. I. E. E., Saratoga Springs, June 23, 1925.

conductor size and configuration, the results are somewhat conflicting among themselves and to some extent at variance with the accepted formulas. While there is a difference of opinion on the subject, no clear proof as yet exists that there is any material error in the established formulas when applied to ideal simple conditions. However, it is clear that the actual determination of this loss for the practical case of long 220-kv. lines is a very complex and difficult matter, since the conditions vary so much both along the line and from day to day.

With the increased study of important tie lines which may carry power in *either direction* and with the proposals for the transmission with the aid of synchronous condensers of amounts of power on high-voltage lines near their *maximum capacity*, the importance and the complexity of the designers' task is just now being realized and the all-important rôle of power factor recognized.

In the field of lead-covered cables, we have to record a most active year of great progress. With the marked advance in 66-kv. cable joints ; the successful operation of a number of high-tension cables in 66-kv. circuits in actual commercial service; and with the growing belief that cable for 132-kv. circuits will be feasible and may soon be available, the whole aspect of the transfer of large amounts of power underground in congested districts is changed. The possibility of the use of these voltages leaves very little to be desired as far as capacity goes. However, the costs are extremely high and the technical details are not yet developed to any final stage.

There has been no marked development, but it is believed that a steady advance is being made in the quality of high-tension cables and, therefore, in the voltage at which cable can be used. In addition to the use of single-conductor cable the principal elements contributing to this advance are greater care in the selection of materials, in the fabrication of the cable particularly the more thorough elimination of air and impregnation with the insulating compound. In the higher-voltage cables there is a distinct tendency toward a fluid impregnating compound. For very high-voltage cables it is proposed that this compound by means of reservoirs along the cable, be kept under a hydrostatic head, the conductor cable being hollow or of open structure to permit flow of compound. Much work has been done on all phases of this subject during the last year and many notable papers have been presented before the Institute.

Development in high-tension insulators, lightning arresters, protective relays and oil breakers proceeds steadily but no especially conspicuous advances are noted.

In spite of the number of years in which electric-power systems have been in general use and the vast numbers of distribution networks, there still exists a lively discussion as to the best type of low-voltage local distribution system—whether two-phase with neutral wire or three-phase with one modification or another.

This brief review should not close without mentioning the closer and closer operating cooperation between the well-known groups of large utilities, such as those in the south eastern States, where many necessary details are being worked out. Much more intimate mutual support is being realized, also the rapid interconnection of utilities by high-voltage lines and the establishment of large base-load plants in the great industrial district east of the Mississippi and west of the Alleghanies. This sort of interconnection is developing interesting and difficult problems in the metering of commercial power.

In accordance with the plan for making the Annual Convention a forum for the informal discussion of topics of current interest without the labor of the preparation of formal papers and without the consumption of the time necessary to present them, the following topics are presented for discussion.

A. What capacity in lead-covered cable can a present-day designer count upon in laying out connections for the transfer of power from a large base-load generating plant in or near a large city to the principal distributing substations? On what voltage, what size of conductor, what operating temperature, etc., would this be based?

B. How much load can be handled over a 100-kv. tie-line connecting two large independent systems and carrying equal amounts of power in both directions with dependence placed on tap-changing devices for the maintenance of stabilized voltage in both systems? Can such tap-changing devices be relied upon where the interchange between the systems is to be automatic in accordance with the variations of load and with the conditions of most economic operation in the two systems combined?

C. What is the exciting cause for mechanical standing waves in a high-tension, long-span line conductor? Is tight stringing necessarily a cause of vibration? What is the relation to conductor size, weight and elasticity? What sort of remedy is theoretically effective?

D. Where a large block of power is to be distributed over a considerable area, is it feasible or desirable to use single-circuit interconnected feeders carried by different routes to accomplish distribution and transmission simultaneously. In such a case, what are the limitations on tapping the single circuit feeders for local loads, the questions involved being relay protection, cost of installation, reliability of service, etc.

E. What can be done to reduce installation cost of high-voltage transmission lines? Can transmission towers be further standardized? Can more mechanical devices be used in hole digging and erection? Is the use of extra high-strength conductors and very tight stringing desirable?

F. What can be done to reduce to reasonable proportions the cost added to a transmission line construction by the necessity of considering the effect of heavy sleet?

Application of Electric Propulsion to Double-Ended Ferry-Boats

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and

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Synopsis.—*The double-ended ferry-boat propelled by means of a bow and stern propeller has become the recognized standard type, due to its maneuvering possibilities and general handiness in congested harbors.*

In all cases in which the prime mover is directly coupled to the two propeller shafts which must necessarily turn at the same revolutions per minute, the over-all propulsive efficiency is lowered due to the performance of the bow propeller.

The electric drive system permits of applying power when and where required and to any degree desired. Tests on the double-ended ferry-boat W. R. HEARST show a material gain in propulsive efficiency when driving the bow propeller electrically at a speed which gives neutral thrust. Later tests indicate, however, that there is no substantial difference in the propulsive efficiency, whether the bow propeller is driven electrically at neutral thrust, or is electrically disconnected and driven by the water. Sufficient tests have not been made, however, to show that this is true in all cases.

The reciprocating steam-engine or Diesel-engine type of drive, in which both shafts are direct connected, require approximately 19 per cent more horse power at the propeller shafts than the electric system, due to the difference in propulsive efficiency.

The calculated fuel consumption of a typical reciprocating steam-engine drive with the direct-connected system shows that it requires approximately 40 per cent more fuel than the steam turbine electric system, due to the difference in propulsive and thermal efficiencies.

The electrical transmission losses are less than the propulsive efficiency losses of the direct systems. In addition to the more efficient method of power application, electric drive also has many inherent advantages, such as rapid maneuvering qualities and ease of control.

The Ward Leonard system, similar to that used on the Chicago fire boats which were put in operation in 1908, permits of the use of pilot-house control, eliminating the personal factor which is always present with the engine-room telegraph.

The operating records of ferry-boats in service prove electric drive to be reliable.

The respective field of application of turbine electric drive or Diesel electric drive for double-ended ferry boats depends upon the relationship of first cost to the operating changes and needs of the service.

The double-ended ferry-boat presents a problem unique in marine and electrical engineering and the data pertaining to the specific applications which follow bring out quite forcibly the manner in which electric drive overcomes the inherent losses of other systems and brings about a higher over-all efficiency than formerly attained in preceding types.

Briefly, the economic gains brought about through the electrification of the main propelling machinery consist of two things:

I. Gain in propulsive efficiency due to the method in which the power is applied to the forward and aft propellers.

II. Gain due to the higher thermal efficiency of the turbo electric and Diesel electric machinery as compared to the reciprocating steam engine.

It has long been recognized by naval architects and marine engineers that an inherent loss in propulsive efficiency exists when one prime mover is directly coupled to a bow and stern propeller, which must necessarily turn at the same rev. per min.

Compromise designs have been made in an attempt to decrease the bow propeller losses, but it is not apparent from published test records that this has resulted in an increased overall propulsive efficiency.

Several tests have been made on reciprocating steam engine driven, double-ended ferry-boats, driving with the stern screw with bow screw removed, pulling with bow screw with stern screw removed, and driving with both screws at the same rev. per min. A comparison of the power input required to give the same boat speed with the various systems is given in Table VI.

Driving with the stern screw with forward screw removed consumes the least power at a given speed. Due, however, to the fact that ferry-boats operate in congested waters and usually on short trips, it is not practical to turn the boats around, and therefore the double-ended arrangement has come into use as being the most practical for this type of service. The double-ended ferry-boat may, therefore, be considered a compromise type, in which high propulsive efficiency is sacrificed for maneuvering ability and general handiness.

As electric power may be applied when and where required and in any degree desired, it is but natural that this type of propulsion finds a ready application in the double-ended type of ferry-boat, as the two propellers may be driven at such relative speeds that the entire work of propulsion be accomplished entirely with the after screw.

The general method adopted in the various electrically driven ferry-boats is the driving of the boat with the after screw and the operation of the bow screw at sufficient rev. per min. to overcome either a pulling or pushing affect.

Tests have been made on the electrically driven ferry-boats and the power input to the bow screw at neutral thrust noted. The results may, therefore, be compared

1. Both of the Marine Engineering Dept., General Electric Co., Schenectady, N. Y.

Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

with the tests previously made on the reciprocating steam-engined ferry-boats.

The electric system is comparable to the one screw arrangement plus the additional power required to drive the bow screw.

As will be shown later by records of tests the increased power required by the two screw arrangement, driving at the same rev. per min., is approximately 25 per cent as compared to driving with one screw, whereas with the electric drive, the bow screw may be operated at neutral thrust with an expenditure of power amounting to approximately five per cent.

The data which follows include a description of the electric equipment, control features and various tests on the following electrically driven boats:—A-c. turbine electrically driven ferry-boats—*W. R. Hearst, Rodman Wanamaker* and *Geo. W. Loft*; d-c. Diesel electrically driven ferry boats—*Golden Gate* and *Golden West*; d-c. turbine electrically driven ferry boats—*Hayward* and *San Leandro*.

The *W. R. Hearst, Rodman Wanamaker* and *George W. Loft* are operated in New York harbor by the City of New York and were placed in service during 1923 and 1924.

The propelling machinery consists of an 8-stage horizontal Curtis steam turbine, direct-connected to an a-c. generator. This generator furnishes power to two double squirrel-cage induction motors, each rated 36/52 poles, 2100/100 h. p., 176/122 rev. per min. The 36-pole winding is used to drive the boat by means of the aft propeller and the 52-pole winding, to drive the forward propeller at or near neutral thrust. The rotor of one motor is direct-coupled to the forward propeller shaft, and the rotor of the other motor is direct-coupled to the aft propeller shaft.

Excitation and power for the electrically-driven auxiliaries, lighting, etc., is obtained from one 125-kw., 220/110-volt, d-c. generator, which is driven by a geared Curtis condensing steam turbine. There is a second set, of the same capacity, which is a spare. Practically all continuous duty auxiliaries excepting boiler feed pump are motor driven.

The control station is located in the engine room. The operator normally controls the ship by means of an electric lever and a speed switch. Emergency levers are provided so that in case of the failure of electric control or the turbine variable speed maneuvering governor, the propelling machinery may be operated by the manually operated levers.

The electric lever controls the solenoid operated contactors and the speed switch controls the governor setting of the turbine.

Due to the exacting maneuvering requirements met on ferry-boat service, the 36-pole induction motor winding was designed to give normal full load torque with super-excitation of the generator field, irrespective of the turbine revolutions per minute or generator frequency. This was accomplished by usinga double squirrel-cage rotor winding. This winding consists of a wiinding having a relatively high resistance and low nductance, electrically, in parallel with a winding of relatively high inductance and low resistance. When starting, the reactance of the low resistance squirrel-cage is high, which causes the current to flow chiefly through the high resistance winding.

At full speed or when the motor has pulled in step, the reactance of the low resistance winding is low and the current flows chiefly through this winding. This permits a relatively high torque at starting and an efficient motor when running in step.

The advantage of this type of motor is that it eliminates brushes, collectors, external resistors and short-circuiting contactors. It is possible to maneuver without slowing down the turbine or generator revolutions, but if this is done, it requires a longer time for the motor to be pulled into step than if the turbine revolutions are reduced.

On July 28, 1923, several reversal tests were made and it was found that with the boat going full speed ahead, the propeller could be stopped in about five seconds from the time the signal was given from the pilot house, reversed and pulled into step in the opposite direction in about ten seconds, and the boat stopped dead in the water in from fifty to sixty seconds. These tests were conducted in New York harbor, and therefore, it was impossible to note the boat's speed and difficult to determine when the boat had come to rest in the water. These readings are therefore mentioned as being approximate and only of general interest.

Before starting tests on the propelling machinery the bow motor was electrically disconnected and readings taken of the stern and bow motor rev. per min. We were unable to estimate the speed of the boat. These readings give the relative rev. per min. of the stern and bow motor when the ship is being propelled by the stern motor, the bow motor being driven by the propeller. When the stern propeller was being driven at 171 rev. per min. the bow propeller drove the bow motor at 100 rev. per min. During and following these tests, the end play of the bow motor was noted. When power was applied the bow motor end play was taken up in a forward direction, occasionally coming aft due to waves, etc. It is believed, therefore, that approximately neutral thrust or a slight pull was exerted when the bow motor was driven electrically.

During the tests on the propelling machinery the following readings were taken:

TABLE I

W. R. Hearst

A-C. Generator				Aft Motor		Forward Motor	
Line Volts	R.P.M.	Field Amps.	Field Volts	Amps.	R.P.M.	Amps.	R.P.M.
2500	3050	135	110	515	165	39	118
2275	3000	125	110	560	167	39	118
2300	3050	125	110	550	168	50	118
2350	3000	130	110	530	165	40	118
2350	2900	130	110	500	158	35	112

Based on factory tests, the calculated power delivered to the bow and stern propeller shafts is as follows:

TABLE II

Aft Motor

Kv-a.	P.F.	Eff.	Kw. Input	Kw. Output
2230	74	94	1650	1550
2207	76	94	1675	1575
2190	76	94	1660	1560
2160	75	94	1620	1525
2036	73.5	93.9	1495	1405

Forward Motor

Kv-a.	P.F.	Eff.	Kw. Input	Kw. Output
169	53	83.5	90	75
153.5	57	84.5	87.5	74
199	64	84.0	127	107
162	57	84.3	92.5	78
143	49	82	70	57.5

The calculated cable loss between the generator and the propelling motors is approximately 1700 watts with full load on the bow and stern motor windings. The combined bow and stern motor full load efficiency is 93.7 per cent at 74.8 per cent power factor. From the results of these tests it appears that when the stern motor was delivering 2100 h. p., the bow motor was delivering approximately 107 h. p., or 5.13 per cent of the power delivered by the stern motor.

Test results check the estimates made by M. G. Kindlund, Naval Architect, based on model tests as well as general estimates made by Commander S. M. Robinson, published in the December 1920, *Marine Engineering*.

The propellers on the *George W. Loft* were of a different design, giving a different relationship of the bow and stern revolutions per minute for neutral thrust. Based on these tests and tests conducted on other electrically driven ferry-boats, it was decided that it is practically as efficient to drive the bow motor by means of the bow propeller as it is to drive the bow motor electrically; that is, instead of having an output of the stern motor of 2100 h. p. and of the bow motor of 107 h. p., practically the same results can be obtained by using the same generator output on the stern propeller motor, which would be equivalent to slightly more than 2207 h. p. output of the stern motor, due to the difference in efficiencies, allowing the water to drive the bow propeller. This permits the use of a single speed motor instead of a double speed motor.

The *Golden Gate* was the first Diesel electric, double-ended ferry-boat to be placed in service and is therefore taken as an example of Diesel electric drive. This boat was placed in service in San Francisco Bay, July 4, 1922.

The electric propelling machinery consists of two Diesel driven, direct-current, separately excited generators, each rated 360 kw., 250 volts, 225 r. p. m., and two 35-kw., 115-volt exciters, each mounted on the shaft extension of the main generators. The generators are normally electrically connected in series. There are two separately excited propelling motors each rated 750 h. p., 145/180 r. p. m. The rotor of one motor is direct-coupled to the forward propeller shaft, and the rotor of the other motor is direct coupled to the after propeller shaft. Either one of the two exciters is used for exciting the generators, propelling motors, control, and furnishing power for the electrically driven auxiliaries, lighting, etc.

The control is of the Ward Leonard or voltage-current system, similar to that first used on the Chicago Fire Boats, *Joseph Medill* and *Graeme Stewart.*

The direction of rotation and rev. per min. of the propelling motors is controlled by varying the excitation of the generator fields and the relative rev. per min. of the bow and stern motor by changing the field excitation of the motors. It is possible, with this type of control, to change the relative bow and stern propeller rev. per min. at any predetermined position of the controller.

There are three control stations; one in each pilot house and the third station located in the engine room.

Normally, the generators are electrically-connected in series but cut-out switches are provided so that either generator may be disconnected, the boat being operated by the remaining unit. The motor field control permits utilizing full output of one engine, which corresponds to approximately 80 per cent propeller rev. per min.

The several severe tests, and also the operating records in normal service, have demonstrated the advantage of pilot house control as well as the reliability of this type of machinery.

This ferry-boat has been stopped from full speed ahead to dead in the water in between 30 to 35 seconds.

More complete tests were conducted on the *Golden West,* which is a sister ship of the *Golden Gate* and has the same propelling equipment. We shall, therefore, use results of the tests conducted on the *M. S. Golden West.*

The following readings were taken April 6, 1923, when running over the measured mile off California City:

GOLDEN WEST TABLE III

		Aft Motor			Forward Motor			Total Motor Excit.			
Run	Line Volts	Line Amps.	R.P.M.	Kw. Input	Line Amps.	R.P.M.	Kw. Input	Fld. Amps.	Fld. Volts	Knots	Remarks
1	475	1138.6	173.3	540	59.3	138.6	28.2	121.7	115	11.75	Against
2	470	1031.6	174	485	88.3	139.5	41.3	122.6	115	12.25	With
3	470	1142	174	537	77	143.2	36	124.2	115	11.5	Against
4	472	1000	172	472	130	144.2	61.2	121	115	12.4	With
5	511.6	1406.6	193.5	718	53.3	157.1	27.1	103.6	115	11.75	Against
6	511.6	1295.3	193.5	661	98.3	158	50.2	98.3	115	5.3	With

TABLE IV
FORWARD MOTOR ELECTRICALLY DISCONNECTED

	Aft Motor			Foward Motor		
Run	Amperes	Volts	R.P.M.	Amperes	Volts	R.P.M.
7	975	480	170.6	0	0	123.7
8	975	475	171	0	0	124
9	1000	475	170	0	0	126
10	1000	475	170	0	0	125
11	980	475	170	0	0	126
12	960	475	170	0	0	126

Based on factory tests, the power delivered to the bow and stern propeller shaft is as follows:

TABLE V

	Aft Motor		Forward Motor		TotalMotor
Run	Kw. Input	Kw. Output	Kw. Input	Kw. Output	Excit. Kw.
1	540	507	28.2	22.5	14.
2	485	457	41.3	35.5	14.1
3	537	505	36	30.2	14.3
4	472	445	61.2	55.1	13.9
5	718	672	27.1	21.4	11.9
6	661	620	50.2	44.3	11.3

Results of these tests show that the average power output of the bow propeller motor was 6.8 per cent of the stern motor. The full load overall efficiency, including generator losses, exciter losses, motor losses, cable losses and rheostat losses, when the stern motor is delivering 750 h. p. and the bow motor 51 h. p., is 83.9 per cent.

Unfortunately, there is no notation on the tests conducted that the bow motor was exerting neutral thrust or a forward pull, but based on the relative rev. per min. of the stern and bow motor when the bow motor was being driven by the water and when the bow motor was electrically driven, we believe that there was a slight forward pull, which may or may not account for the slightly higher power input to the bow motor than that shown on the tests conducted on the *W. R. Hearst.*

The *Hayward* and *San Leandro*, which were placed in service on San Francisco Bay in 1923, are of the d-c. turbo-electric type.

The electric propelling machinery consists of a 1100-kw., 3600-rev. per min., horizontal, Curtis steam turbine direct-connected through a reduction gear to a 1000-kw., 900-rev. per min., separately excited generator. Mounted on the shaft of the main generator is a 75-kw., 115-volt exciter. The 1000-kw. generator supplies power to two separately excited, double armature motors, each rated 1200 h. p., 100 to 125 rev. per min. The armatures of one motor are direct-coupled to the forward propeller shaft and those of the other motor to the aft propeller shaft.

The 75-kw. generator supplies power for exciting the 1000-kw. generator, the two propelling motors, control, auxiliary power and lighting.

The control station is located in the engine room, and the control is of the Ward Leonard or voltage-control system, similar to that described for the Golden Gate ferry boat.

The above boats have been in continuous operation since their inauguration into service. As an example of the severe duty required of these boats, the following data, covering a short period of their operation, are given.

Between May 31, 1923 and February 10, 1924 the *Hayward* made 10,500 trips, traveled 30,312 miles and carried upwards of 4,000,000 passengers. The two boats, in a year's time, carry upwards of 10,000,000 people and the largest number of people carried in one day by one boat has aggregated upwards of 30,000 people. They serve one of the most congested terminal traffic lanes in the world. Six hundred and fifty electric trains per day serve the traffic at the Oakland Terminal and during the one hour rush period between five and six o'clock in the evening, 48 trains are moved.

The operating record of these boats is given rather than a repetition of test data on the previous boats, due to the fact that it brings out one very essential point, that is,—the absolute reliability of this type of machinery where continuity of service is the paramount factor.

Comparative Efficiencies

The following section is devoted to an analysis and economic comparison of the reciprocating steam engine driven and turbo-electric driven types of ferry-boats.

This will tend to show in a concrete way the fundamental differences that exist due to both the propulsive and thermal factors.

The Diesel electric system has the same advantage as the turbo-electric drive in the matter of gain due to the difference in propulsion characteristics. The high thermal efficiency of Diesel engines, as compared to either the reciprocating steam engine or turbo-electric, is fully recognized, but due to the fact that this subject has been so fully covered by the Diesel engineers, it is omitted from this paper.

The selection of steam turbines or Diesel engines depends upon the relationship of first cost to operating costs, the needs and requirements of the service, and is also influenced, to a more or less extent, by the past experience of the operating companies.

Relative Power Requirements. The relative power required to maintain a given boat speed, as ascertained by tests made on the reciprocating steam engine driven type of double-ended ferry-boats, is given in Table VI.

Conclusions to be Drawn from Tests

A. Propelling with bow screw, stern screw removed: The tests show that over 50 per cent more power is required when pulling with the bow screw than when pushing with the stern screw.

B. Pushing with stern screw, bow screw removed: This method takes the least power and may, therefore, be considered the base with which to compare other

TABLE VI

Knots	A Pulling with Bow Screw, Stern Screw Removed I. H. P	B Pushing with Stern Screw, Bow Screw Removed I. H. P.	C Propelling with Both Screws at the same R.P.M. I. H. P.
Ferry-Boat *Edgewater*			
8	255	178	222
9	370	245	312
10	560	345	440
11	850	500	612
12	1270	740	840
Ferry-Boat *Cincinnati*			
9	443	250	332
10	638	364	464
11	880	520	624
12	..	720	816

References: Trial trip data of *Edgewater* from paper presented by E. A. Stevens and Chas. P. Paulding, before Society of N. A. & M. E., November 20. 1912.

Trial trip data of *Cincinnati* from paper presented by F. L. Du Bosque before Society of N. A. & M. E., November 12-13, 1896.

systems. In service, however, this system is not practical.

C. Driving with bow and stern screw at same rev. per min.: The tests disclosed that approximately 25 per cent more power is required to maintain the same speed of boat than in system "B". This is the usual method of propelling a double-ended ferry-boat in which the prime mover is directly connected to the two propeller shafts.

D. Driving with after screw only, bow screw operated to give neutral thrust; electric drive system only: The series of tests conducted on the electrically driven ferry-boats disclose the fact that the bow propeller may be operated to give neutral thrust with an expenditure of power amounting to approximately five per cent of the total.

In service, we are interested only in systems "C" and "D". As the relation between these two systems is of the order of 125 per cent to 105 per cent, taking the electric drive system as the base, the new relation becomes 119 per cent and 100 per cent, respectively.

In other words, the electric drive system requires but 84 per cent as much power as the reciprocating engine drive to attain the same boat speed, due to the gain in propulsive efficiency.

Analysis of Steam and Fuel Consumption

The 2200-s. h. p. turbine electric, a-c. driven ferry-boat has been selected to compare with a reciprocating, steam engine driven ferry-boat as water rate and efficiency tests were conducted at the factory on the electrical equipment. The s. h. p. required by the reciprocating engine driven type to be comparable will be 2620. On account of the long line shafting required in the latter type, a mechanical efficiency of 90 per cent is assumed, which gives an i. h. p. of 2910.

Comparative Water Rates of Main Propelling Machinery:

a. Reciprocating steam engine; so far as the authors are aware, there have been no data published regarding water rate tests of reciprocating steam engines installed on ferry-boats in which either the power developed or steam conditions are comparable to the turbine electric installations. Recourse, therefore, must be made to such formulas as Jenson's or the later methods deduced by E. A. Stevens, Jr.

Average values range from 14 to 17 lb. per i. h. p-hr. for saturated steam at 250-lb. gage pressure, and correcting for 200 deg. fahr. superheat, these values are reduced to 11.5 to 14 lb. per i. h. p-hr.

In the comparisons which follow the minimum value of 11.5 lb. per i. h. p-hr. is used.

b. The water rates of the turbo-electric equipments furnished for the New York municipal ferries were determined by a very rigorous series of tests. This amounted to 10.135 lb. per s. h. p. per hr. including the generator and motor losses, with the hand valves open. Under the following steam conditions—pressure 250 lb. gage, superheat 200 deg. fahr., vacuum 28.5 in.—quite a throttling loss takes place at rated full load with

TABLE VII

	Reciprocating Engine	Turbine Electric a-c.
S. h. p.	2620	2200
I. h. p. (Mechanical efficiency 0.90)	2910	
Water Rate lb. per hp-hr.	11.5 (I.H.P.)	10.0 (S.H.P.)
Steam Consumption lb. per hr..		
Main propelling unit	33400	22000
Auxiliary turbine generator	1620	2194
Steam auxiliaries	2960	2625
Total lb. per hr.	37980	26819
Lb. per I.H.P—All purposes	13.5	..
Lb. per S.H.P—All purposes	14.5	12.2
Evaporation per lb. oil	12.8	12.8
Lb. fuel oil per hour	2970	2100
Lb. fuel oil per i.h.p-hr.	1.02	..
Lb. fuel oil per s.h.p-hr.	1.135	0.955
Difference, lb. fuel oil per hr.	870	
Difference, tons per 24 hrs.	9.35	
Relative fuel consumption	142%	100%

TABLE VIII

AUXILIARIES	Reciprocating Engine	Turbine Electric
Varying with type	Lb. per hr.	Lb. per hr.
Feed Pump	1000	725
Steam for heating fuel oil	210	150
Constant for both types		
Service Pumps	1750	1750
Total lb. per hr.	2960	2625
Electric Auxiliaries:	Kw-Hr.	Kw-Hr.
Varying with type:		
Circulating pump	15.0	30.0
Condensate pump	7.5	5.0
Excitation	0.0	15.0
Blower for motor ventilation	0.0	13.0
Constant for both types		
Lubricating oil pump, lights, Sanitary pump, fresh water pumps, Steering gear, Ventilating fans	37.5	37.5
Total Kw	60.0	105.5
W/R	27.0	20.8
Lb. Steam per hr.	1620	2194

the hand valve open. With the hand valve closed, in which rated full power is available, the water rate is 9.98 lb. per propeller shaft horse-power hour. In the comparisons which follow a flat rate of 10.0 lb. is used. (The hand valve is used for overload conditions during rush hours.)

Conclusions

1. That the reciprocating steam engine or Diesel engine, in which the bow and stern propellers are operated at the same revolutions per minute, require approximately 19 per cent more power than the electric system, due to difference in propulsive efficiency.

2. That the fuel consumption of the reciprocating steam engine drive with the direct connected bow and stern propellers requires approximately 40 per cent more fuel than the turbine electric system, due to the difference in propulsive and thermal efficiencies.

3. That the operating records of the boats in service prove electric drive to be reliable and a great step forward as a method of propulsion for the double-ended type of ferry-boat.

4. That in the comparison of turbo d-c. and a-c., the d-c. is superior in flexibility, simplicity of control and general handiness afforded by bridge control. That the a-c., however, is slightly more economical as regards fuel consumption.

5. That both turbo-electric and Diesel-electric drive overcome the inherent propulsive efficiency loss of the reciprocating steam engine type of drive and that their respective spheres of application are dependent upon the relationship of first cost to operating charges, and needs of the service.

The Activities in Research

By Committee on Research[1]

Part I. General

Activity in the field of electrical research, as noted in last year's report, has continued unabated during the past year. The range of problems has been much the same, and while no striking research of outstanding importance may be mentioned, noteworthy progress has been made in many directions.

In the field of high-voltage transmission and power distribution there is an increasing tendency to investigate the performance of such systems through experimentation with models, miniature systems and equivalent net works. With these should also be included several important analytical studies of the transients occurring in such systems. Several accounts have appeared of experiences with 220-kv. systems based on special methods of observation and measurement, and these have brought forward facts and conditions sufficiently new to warrant their mention in this report. Important new data are available as to lightning disturbances and methods of protection; a new type of suspension insulator of great promise has appeared and further studies have been made of the properties of protective reactors. New data as to the law of loss due to corona have been brought forward and definite statements made as to the value of corona as a stabilizing, if not a protective measure for high voltage systems.

In the wide field of magnetism much new material has been produced. Investigations have extended from studies of the core loss in induction machinery, the losses in laminated surfaces next to air gaps, the influence of slot openings on wave form, and other similar questions in machinery, to the further study of the properties of magnetic materials in relation to their constituent substances. Noteworthy in this class is the substance permalloy and its adaptation to the submarine cable; a thing of great promise, but so far, upon this relatively little definite information is available. An important accomplishment in this field is the completion of a complete bibliography of the literature by the Core Loss Committee of the National Research Council. The bibliography embraces all branches of the field of core losses and is admirably classified and indexed. It is hoped that some one of our large research organizations will find it possible to publish this bibliography so that it may become generally available.

Among other studies in the general field of electrical engineering there may be mentioned as either completed or under way the following variety of problems: The influence of impurities in storage battery electrolytes; many studies of rectifying devices, including further methods of obtaining high, continuous voltage; the construction of an absolute electrometer for very high voltages; a redetermination of the unit of resistance, (these two latter at the National Bureau of Standards); the determination of the temperature errors in induction wattmeters, and other important developments in methods and instruments of measurement.

In the field of electrical communication special mention should be made of the increasing expansion of research work carried on by the Bell Telephone Laboratories. The range of problem handled in these laboratories is extremely wide and very noteworthy contributions are appearing at regular intervals. These are not confined to the immediate problems of conversion

1. Annual Report of Committee on Research.

John B. Whitehead, Chairman

Edward Bennett,	C. I. Hall,	E. W. Rice, Jr.,
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Presented at the A. I. E. E. Annual Convention, Saratoga Springs, N. Y., June 22-26, 1925.

between speech and electric circuits and vice versa, but reach out into the field of pure physics on the one hand, and to studies of the performance characteristics of all types of electric circuit on the other. Of special note is our increasing knowledge, obtained through these laboratories, of the performance of all types of circuits under a very wide range of frequency, and the development of filters, relays, and other forms of auxiliary equipment for circuit control for special purposes.

Extension of range and improvement of methods, in radio, telegraphy and telephony is of almost daily occurrence. It is a highly specialized field, but one in which, many members of the Institute are nevertheless participating. Among the great number of improvements in transmitting and receiving equipment, there stand out as of recent, more conspicuous achievements, the control of static in transatlantic service; the increasing use of the shorter wave lengths; the control of "fading;" and the further perfection of generating equipment.

In the field of pure physics, principal attention appears still to be devoted to questions of molecular and atomic structure and the nature of the ultimate constitution of matter. Progress has been very rapid and the results obtained are of greatest importance as well as of absorbing interest. Up to this time, however, these studies do not appear to touch, in any close manner, the laws underlying the various arts in electrical engineering. It is an interesting fact that while much certain knowledge has been gained, as to the structure of the atom and the electrons therein, nevertheless it has not been found possible to adapt this knowledge in any certain way to explanations of the great fundamental phenomena of electric conduction, magnetism, and dielectric induction. For this reason, as well as because of the vast variety and quantity of material, only this passing mention is made of this great field of the highest type of scientific research.

Part II. Electrical Insulation

This report has reserved for separate comment the subject of research in the field of electrical insulation. The year has seen a notable continuance of the general interest in this important problem. Numerous papers have been published giving new technical data, thus slowly increasing our knowledge. Among the subjects treated may be mentioned distribution of flux density in cables, the relation between breakdown voltage and times of application and rest, experimental data on the breakdown of cable insulation under standard tests with special reference to the duration of application of the test voltage, the influence of temperature on impregnated paper insulation, and ionization in impregnated paper insulation. Discussion of these papers has indicated the desirability of certain changes in present tests standard for high-voltage cables.

Particular mention should be made of the work being done by the committee of the National Electric Light Association on Cable Insulation Research. This committee has formulated a well considered plan and has raised sufficient money to pay for "whole-time" research assistants, the work to be carried on in the electrical engineering laboratories of Harvard University, Johns Hopkins University and Massachusetts Institute of Technology. Problems of attack are those bearing on the life of high-voltage cable insulation and the causse of its failure,—work is certain to produce results of value.

As indicated in last year's report, the Committee has had before it as its principal object the complete review and digest of the literature of electrical insulation. This work, formulated first by the Engineering Division of the National Research Council, in its Committee on Electrical Insulation, is being carried on largely by members of the Committee on Research of the American Institute of Electrical Engineers. The particular value of this work will be found in the summaries and conclusions to be prepared by the chairman of the several committees. The Committee hopes to include in these summaries statements as to the present problems under the respective headings, with suggestions for the most profitable lines of experimental attack. Steady progress has been made, although it can scarcely be said to be rapid; the character of the undertaking is such as to require considerable time and sustained effort. Surveys in the field of insulation can be made only by experienced and competent men, and under our present plan, we are relying entirely on the voluntary efforts of a comparatively small number. All of these are busy men with whom the work of the Committee must, of necessity, take a subordinate place.

The present state of the work is approximately as follows: The Sub-Committee on Dielectric Absorption, J. B. Whitehead, Chairman, has practically completed its review of literature; Sub-Committee on Phase Difference, Delafield DuBois, Chairman, has completed about eighty-five per cent of the literature; on Electric Strength, W. A. Del Mar, Chairman, has completed all the literature on solids, and its report is well advanced towards completion. The review of literature on liquids is well advanced. The Sub-Committee on Flash Over Voltage, F. W. Peek, Jr., Chairman, has covered the field of the literature in English, and is making progress in foreign literature. The Sub-Committee on Theories, J. B. Whitehead, Chairman, has practically completed the review of the literature. The Sub-Committees on Dielectric Constant and on Resistivity have not been able to make any considerable progress.

The reviews of the literature referred to above consist of a separate report in standardized form for each paper reviewed. The results of this work therefore will constitute not only a valuable bibliography of the separate divisions of insulation, but also a most valuable concentration in one place of the important results of each worker, and, therefore, a combined picture of the entire problem which should prove of very great value.

As the publication of this large mass of data will be a matter of some expense, the Committee hopes to make the more important results of its work available to all through the preparation of reviews and summaries by the respective chairmen.

PART III. THE ORGANIZATION OF RESEARCH

A general review of the work in electrical engineering research during the past year reveals two striking facts: First, the great amount of experimental research under way and the wide range of problem; and second, the lack of coordination among various workers in the same or allied fields. Obviously, a function of the Committee on Research should be the bringing about of such coordination if in any way possible. The difficulty here is in obtaining information as to the work undertaken in widely separated localities. Often the Committee's first knowledge of a piece of work is the appearance of the paper presenting the results. This state of affairs must continue so long as the original conception of the problem arises in the interest of some individual, in a university laboratory, or in the special needs of some manufacturing process.

The foregoing condition has been recognized for some time and the desirability for organization and coordination of electrical research has been frequently emphasized; in fact, the National Research Council in its Engineering Division, the Engineering Foundation, the National Bureau of Standards, and, to a less extent, the national engineering societies, all conceive it their definite function not only to stimulate but to coordinate research. The Committee on Research of the Institute acts as an advisory committee on questions of electrical engineering to the Engineering Division of the National Research Council, the body which initiated the work on electrical insulation. In addition to the Committee on Electrical Insulation, it has formed a number of other important committees, not only in the electrical, but also in other fields of engineering. If the purposes of these committees are carried out, they will result in authoritative statements of the problems in the various fields, will serve as important guides for future work, will avoid duplication of effort and, naturally, will result in a much more rapid extension of our knowledge in the respective fields.

The picture so presented is an inspiring one, but it has one serious and fundamental defect. On closer examination it will be found that the function of the comprehensive review of the field of any problem is relegated to volunteer workers. The men who are capable of making these studies and reviews, and of laying out subsequent programs, occupy important positions the duties of which must necessarily require most of their time; committee work of necessity takes a subordinate place. Money has been appropriated for particular research problems, but none for greater expert reviews of the entire field. This is unfortunate, the more so since it should not require any considerable annual expenditure to avoid it. The Committee on Research has spent nearly two years in accumulating data on insulation outlined above. This could have perhaps been done in one-fourth of the time by a single well trained man devoting his entire time to it.

The concrete suggestion, therefore, is that large organizations, the chief function of which is to promote experimental research, could, with profit, maintain as a part of their organizations a few competent men trained in science, engineering and in the methods of research, with their principal duty the presentation of the work of the past, problems of the present, and plans for concerted experimental attack for the future. The volunteer research workers would do the rest.

Revised Standards and the Organization of Standards Activities

By Standards Committee[1]

GENERAL REVISION OF THE STANDARDS

DURING the past three years the attention of the Standards Committee has been focused primarily on a general revision of the Institute Standards, both as to form and content. In form the revision is far reaching, involving the preparation in separate pamphlets of the standards relating to different types of apparatus or to different branches of the art.

The extent to which this subdivision has been carried is indicated by the fact that the revised standards now planned will, when all are completed, constitute about forty different sections. For example, the Standards for rotating machinery are covered by a half dozen different pamphlets giving, individually, Standards for Synchronous Alternating-Current Machinery, for Induction Motors, Direct-Current Machinery, Fractional Horse Power Motors, Synchronous Converters and for Railway Motors. Another section deals with Standards for Transformers and Induction Regulators. The Standards for Industrial Control Apparatus and for

1. Annual Report of the Standards Committee.

H. S. Osborne, Chairman
H. E. Farrer, Secretary, 33 W. 39th St., New York, N. Y.

J. D. Bowles,	A. M. MacCutcheon,	L. T. Robinson,
W. A. Del Mar,	J. Franklin Meyer,	C. H. Sharp,
H. M. Hobart,	F. D. Newbury,	C. E. Skinner,
G. L. Knight,	Harold Pender,	R. H. Tapscott,
	F. L. Rhodes,	

Ex-Officio

President, U. S. National Committee, I. E. C.
Chairmen of Working Committees of Standards Committee.
Chairmen of A. I. E. E. delegations on joint standardizing bodies.

Presented at the A. I. E. E. Annual Convention, Saratoga Springs, New York, June 22-26, 1925.

Railway Control Apparatus are in separate sections. Standards for Wires and Cables, for Telephony and Telegraphy, and for Storage Batteries occupy one section each.

Certain of the sections deal with general matters. For example, one section includes the Standard Definitions and Symbols; another the Principles upon which Temperature Limits are Based in the Rating of Electrical Machinery; and another, Standards for the Measurement of Test Voltages in Dielectric Tests.

Advantages of the Revision

The added convenience of the standards in their revised form hardly requires comment. Not only does it make it unnecessary for one to have at hand all of the Institute Standards in order to have available those specifically applicable to a particular type of apparatus, but the fact that the Standards relating to each type of apparatus are condensed into a small pamphlet makes it vastly easier to determine beyond doubt what are the standards applying to that type of apparatus, a determination which, with the growth of the Institute Standards in their old form to a sizable volume, had become a task, in spite of an excellent index.

Furthermore, the subdivision of the standards has an essential effect on the ease with which they can be revised, it now being possible to make revisions in the standards dealing with each class of apparatus without involving changes in a large book.

Perhaps the most important effect of the revision, however, is the extent to which it facilitates cooperation with other organizations interested in electrical standardization. There is no other single organization actively interested in all of the Institute Standards, as the Institute alone covers broadly the field of electrical industry. However, with regard to almost any individual section of the revised Standards, there are one or more organizations doing standardizing work in an allied field or in a field so closely identified with it as to form desirable copartners with the Institute in the formulation of standards. The American Electric Railway Association, for example, is directly interested in the Standards for Railway Motors and Railway Control Apparatus, but would not care to participate in standardizing work in most of the other fields covered by the Institute Standards. The Standards for Industrial Control Apparatus, touch a field in which the Electric Power Club is very active, and the present Standards were formed by the Institute and the Power Club, acting in cooperation, and have been adopted by both bodies.

From the standpoint of content of the Standards, having them subdivided to deal with specific types of apparatus or branches of the art makes it possible to have more specific standards for the particular type of apparatus than heretofore. For example, the temperature limits to be observed in the rating of electrical apparatus which heretofore, in the Institute Standards, have been based rather largely on general temperature limits for different classes of insulation in the revised standards are made specific to types of apparatus as agreed upon as most desirable by all branches of the industry concerned with that type of apparatus.

Changes in the Content of the Standards

In carrying out so complete a revision of form and arrangement of the Standards, there have naturally resulted a large number of changes in contents. For the most part these changes consist of additions or of more complete discussion of matters included in the 1922 Standards and clarifications.

The additions are so numerous and so important that they are discussed more fully a little later. A good example of clarification is presented by the fact that in the revised Standards, in the discussion of the temperature limitations of electrical machinery, an attempt has been made to distinguish more clearly between the conditions applied in determining the rating of machinery and safe temperature limits at which machinery may operate. This is, of course, not a new idea but, although present in the 1922 Standards, it was not heretofore set forth as clearly as might be desired. In the revised standards an attempt has been made to set forth more definitely this distinction between rating and operation. A limiting amount of temperature rise under test conditions has been established without qualification as the basis for determining rating in so far as this is affected by temperature. Under some conditions temperature rise greater than the rating limit may be safe and satisfactory, or, in extreme cases, a lesser temperature rise may be unsafe, depending on the different surrounding conditions of service.

In addition to the numerous changes and clarifications a considerable number of changes have been made in content where the present state of the art showed that a revision of the former standards was desirable. These changes are too numerous to detail here but it is of interest to point out a few illustrative examples of the changes which have been made.

Following the discussion at the Niagara Falls Convention, there was some revision of the temperature limits for large machines using Class B insulation. For example, the 1922 Standards state that the limiting temperature for Class B insulation is, in general, 125 deg., but that it is recognized that under some conditions, the insulation may be used successfully at maximum temperatures of 150 deg. or even higher. In the revised Standards, the temperature rise for rating is quite definite for each class of apparatus and the maximum for windings, 80 deg. rise, corresponds

to 130 deg., hottest spot temperature at an ambient temperature of 40 deg., the standard ambient temperature of the 1922 Standards.

An important addition to the Standards for large rotating machines is the detailed specification of the conditions under which embedded detectors should be used for determining temperature rise.

In the standards for small motors recognition is made of the discussion now under way regarding the desirable temperature rise to be used in establishing rating for general purpose motors. The Institute will, of course, adopt revised standards for the temperature limits to be used in the rating of general purpose motors when these are mutually agreed upon by the various organizations interested.

Additions to the Standards

As mentioned herein, the revised Standards contain a large amount of additional material of value. In such well developed standards as those for transformers or for rotating machinery, a few valuable points are added. For some subjects there are entirely new sections. It is, of course, out of the question to list all of even the more important additions but a few examples may be given.

In the section dealing with synchronous machines, there are additions giving the allowable variation from rated voltage, and defining starting and synchronizing kilovolt-amperes. The Standards for Transformers include a rule for defining a circuit with grounded neutral and voltage tests for transformers with graded insulation intended for use on circuits of this type. In a number of the sections of Standards are included definitions of different types of duty superseding the 1922 definition of duty cycle operation.

Many of the types of apparatus, which in the 1922 Standards were covered largely by the general provisions, are now covered very much more specifically. A good illustration of this is the Standards for Industrial Control Apparatus mentioned herein. The Standards for Arc Welding Apparatus are another good example of standards for a type of apparatus which, in the 1922 Standards, was covered only by general provisions. These Standards were prepared in cooperation with the American Bureau of Welding.

A very long list of these important additions could be prepared. For the sake of brevity, however, there will be mentioned only two more sections which are perhaps the best examples of the new material which has been brought into the Standards in this revision. The section dealing with Standards for Tests of Insulators is wholly new and gives standard test methods for determining the performance of both pin and suspension type insulators. The Standards for Electrical Measuring Instruments are another good illustration of an important addition to the Institute Standards. These are based largely on the work of the Technical Committee on Measuring Instruments, reported in the 1924 Convention.

With the continuance of the work on the Institute Standards, a number of other subjects hitherto touched upon very lightly, if at all, will be covered.

Organization of the Work of Revision

The following table is of interest, showing the sections of the revised Standards which are available

TABLE OF REVISED STANDARDS NOW AVAILABLE
or Which Will Become Available During the Summer

Committee in General Charge of Laying out The Revision of Standards
H. M. Hobart, Chairman, C. O. Mailloux, F. D. Newbury, E. B. Paxton

Designating No. of Section	Title of Section	Chairman of Working Committee
* 1	General Principles Upon Which Temperature Limits are Based in the Rating of Electrical Machinery.	H. S. Osborne
2	Standard Definitions and Symbols.	J. B. Taylor
* 5	Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General.	W. I. Slichter
* 7	Standards for Alternators, Synchronous Motors and Synchronous Machines in General.	Harold Goodwin
* 8	Standards for Synchronous Converters.	J. C. Parker
* 9	Standards for Induction Motors and Induction Machines in General.	P. M. Lincoln
* 10	Standards for Direct-Current and Alternating-Current Fractional Horse Power Motors.	H. V. Bozell
* 11	Standards for Railway Motors.	N. W. Storer
* 13	Standards for Transformers, Induction Regulators and Reactors.	J. D. Bowles
* 14	Standards for Instrument Transformers.	G. A. Sawin
* 15	Standards for Industrial Control Apparatus.	H. D. James
* 16	Standards for Railway Control and Mine Locomotive Apparatus.	R. S. Beers
* 19	Standards for Oil Circuit Breakers.	B. G. Jamieson
* 22	Standards for Disconnecting and Horn Gap Switches.	B. G. Jamieson
29	Standards for Electric Railways.	Reprinted from 1922 Edition
30	Standards for Wires and Cables	W. A. Del Mar
33	Standards for Electrical Measuring Instruments.	G. A. Sawin
* 34	Standards for Telegraphy and Telephony	Reprinted from 1922 Edition
* 37	Standards for Illumination.	Reprint of Standards of the Illuminating Engineering Socety Adopted by the A. I. E. E.
* 38	Standards for Electric Arc Welding Apparatus.	F. M. Farmer
* 39	Standards for Electric Resistance Welding Apparatus.	F. M. Farmer
* 41	Standards for Insulator Tests.	R. E. Argersinger
	Miscellaneous Standards.	Reprint of the Standards of the 1922 Edition not Covered in the Above Sections.

*Sections of the Standards available in pamphlet form as of September 15, 1925.

now or which will become available during the summer and giving the name of the chairman of the Working committee in charge of each section. At the head of the list is placed the working committee under the chairmanship of H. M. Hobart in general charge of laying out the revision of the Standards, including both the subdividing into sections and the general scope and arrangement of each section. We cannot too emphatically express our appreciation of the devoted effort which Mr. Hobart and his committee have put into this work and of the conscientious study given to the Standards by the various working committees.

Other Activities of the Standards Committee

Emphasis must also be placed in this year's report on the general revision of the Institute Standards. Some mention should be made, however, of some of the other important activities of the Standards Committee. As the Standards Committee is charged with the general coordination of all standardizing work of the Institute, an important part of its work is the handling of the Institute's relations with the American Engineering Standards Committee. Subject to the approval of the President and the Board of Directors, the Standards Committee acts upon all matters of Institute representation, selection of committees, acceptance of sponsorships, organization of sectional committees, request for approval of standards as American standards, etc.

During the past year the American Engineering Standards Committee has approved as American standard the Standard Symbols for the Wiring of Buildings, for which the Institute is a sponsor. The Institute is now sponsor for nine projects organized under the rules of the American Engineering Standards Committee and has representation on twenty-three additional sectional committees. The chairman of the Institute delegation on each of the sectional committees is an ex-officio member of the Standards Committee.

The Standards Committee works also in very close cooperation with the United States National Committee of the International Electrotechnical Commission. Following the meeting in London last fall, a large number of questions which are before the I. E. C. were presented by the United States National Committee to the Standards Committee for consideration and a large amount of work was done in preparing information for the guidance of the American delegates at the meeting of the I. E. C. at The Hague in April 1925.

Attention has been given by the Standards Committee to the closest possible coordination between its work and that of the Technical Committees. Although some of these committees do not have a very close relation to standardizing work, other committees are engaged in development work which forms a background for new standards. At the invitation of the Standards Committee, the Technical Committees have each appointed a member to serve as a definite point of contact with the Standards Committee. This representative is in effect an ex-officio member of the Standards Committee, receiving copies of the minutes and of the order of business of proposed meetings of the Standards Committee and being always welcome at those meetings.

Conclusion

The present organization of the Standards Committee was set up by the Board of Directors in 1922, in view of the increasing complexity of the standardization work in which the Institute was directly concerned, in order to bring about a complete coordination of the Institute's standardizing activities. It is believed that the present organization is admirably suited to this purpose.

The Executive Committee of the Standards Committee is in effect a purely administrative body, coordinating the work of various organizations. These include the working committees of the Standards Committee who formulate Institute Standards, the representatives of the Institute on sectional committees who are cooperating with representatives of other American organizations under the procedure of the American Engineering Standards Committee, the representatives of the Institute on the United States National Committee of the International Electrotechnical Commission who are cooperating with representatives of electrical industries of this and other countries in the preparation of international electrical standards, and the Technical Committees of the Institute who in many cases are doing fundamental work leading toward the possibility of further standardization in new fields. Furthermore, in the organization of its working committees, the Standards Committee purposes to enlist the fullest cooperation of other organizations interested in their work and makes a practise of advising these organizations in advance of the work proposed and suggesting that any organizations interested designate, formally or informally, representatives to be appointed to the working committee to cooperate in its work.

This is necessarily a large and a complicated structure, the membership of the Standards Committee including directly representatives of 58 different standardizing committees or commissions and these committees having a total membership of over nine hundred not excluding as duplicates men who are on more than one committee. Through the coordinating work which is possible under the present organization of the Standards Committee, however, it is believed that excellent progress is being made.

Induction from Street Lighting Circuits
Effects on Telephone Circuits

BY R. G. McCURDY[1]
Associate, A. I. E. E.

Synopsis.—*This paper discusses series street lighting circuits from the point of view of their relations to nearby telephone circuits. These lighting circuits often have a much greater inductive influence in proportion to the amount of power transmitted than have most other types of power distribution or transmission circuits. This is due to the relatively large distortion in wave shape of voltage and current on certain types of these lighting circuits, and to the unbalanced voltages to ground which occur with series layouts. Three general types of lighting circuits are discussed. These are a-c. arc circuits, d-c. arc circuits supplied by mercury arc rectifiers, and alternating-current incandescent circuits. Of these, the incandescent type of circuit, in which the lamps are equipped with individual series transformers or auto-transformers, is the most important in this respect. Measures for reducing interference from these circuits are discussed. It is hoped that the information given in the paper will be useful to power and telephone engineers in their cooperative efforts to solve these difficulties.*

* * * * *

Introduction

Inductive interference from series street-lighting circuits was one of the first interference problems which confronted the telephone engineer and arose very early in the development of the power and telephone industries. Then, as now, these lighting circuits contributed a much larger amount of interference to exposed telephone circuits in proportion to the amount of power transmitted than most other types of power distribution[2] or transmission circuits. This is due to the relatively large distortion in wave shape of voltage and current on certain types of these lighting circuits, and to the unbalanced voltages to ground which occur with series layouts. Exposures of telephone circuits to this type of power circuit occur more frequently in or near towns which are naturally the terminals or repeater points of toll telephone circuits, which tends to emphasize the importance of this kind of exposure. Moreover, these exposures are often irregular, the layouts being frequently changed due to adding and removing lamps, which makes it difficult, and often impracticable, to coordinate transpositions in the lighting and telephone circuits, a remedy commonly employed in other types of inductive exposure.

Three types of series-lighting circuit are of interest in this problem and are discussed in detail later in the paper. These are a-c. arc circuits, d-c. arc circuits supplied by mercury arc rectifiers and a-c. incandescent circuits. The last type of circuit may also be divided into two classes in one of which the lamp filaments are metallically in series with the line and the second in which they are connected to the secondaries of individual series transformers or auto-transformers. In the straight series circuit the lamps are bridged by film cut-outs which break down and close the circuit when the lamp fails; in the individual transformer or auto-transformer type the transformer is usually operated with open-circuited secondary in case of lamp failure. High-current lamps of the higher candle-power ratings are normally used in connection with the individual transformer type of circuit.

The a-c. arc is now practically obsolete and very few installations remain. In the present state of the art, the d-c. arc and the high candle-power incandescent circuits with individual transformers are used mainly for high-intensity "white-way" lighting in downtown districts, where both the supply and telephone circuits are in cable. Lighting circuits in the outlying districts of cities where both the lighting and telephone circuits are of open-wire construction are more often of the straight series incandescent type. This is a fortunate circumstance with respect to inductive interference which will be apparent from the detailed discussion of the characteristics of the various systems. However, a serious problem is presented by the number of cases which occur, where both the lighting and telephone circuits are in open-wire and the lighting circuits are either of the arc lamp type supplied by mercury-arc rectifiers, or of the incandescent-lamp type equipped with individual transformers. As the general trend of development is toward the use of higher intensities and toward the extension of highway lighting, the importance of the problem seems to be increasing.

While there are a few cases in which these series circuits are supplied directly from constant potential sources, as a rule a constant-current regulating transformer or regulating reactor is used to maintain a constant current, the terminal voltage varying with the load. The reactance of this transformer is normally large as compared to an ordinary constant potential transformer, particularly when the circuit is only partly loaded, which is often the case in order to provide for flexibility and growth. The reactance of this regulating transformer has an important effect on the wave shapes in the a-c. circuits.

In the discussion which follows, the different types

1. Department of Development and Research, Am. Tel. & Tel. Co., New York, N. Y.

2. A discussion of the inductive effects of distribution circuits generally is given in a paper "Power Distribution and Telephone Circuits—Induction and Physical Relations," by H. M. Trueblood and D. I. Cone, to be presented at this Convention.

Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

of circuit are treated separately. Multiple street-lighting systems are not discussed in this paper as it is considered that the problems involved are not materially different from those arising with other multiple lighting systems.

A-C. Arc Circuits

Distortion of wave-shape in a-c. arc circuits is chiefly due to the non-linear characteristics of the arc.[3] On account of the high reactance of the constant-current regulator, the current wave is maintained approximately sinusoidal. Every time the current wave passes through zero, it is necessary for the voltage to build up in order to reestablish the arc; the voltage then decreases as the current increases to its maximum. The voltage again increases as the current decreases, a second maximum of voltage being reached just before the current passes through zero. The voltage wave thus contains two peaks in each half wave occurring immediately before and after the current goes through zero. As a result, the voltage wave on the circuit contains a complete series of odd harmonics, the magnitudes decreasing with increasing order but continuing large within the voice-frequency range.

Each lamp on the circuit contributes to the distortion. If the lamps are distributed approximately uniformly along the circuit, the harmonic voltages to ground at the regulator terminals will be equal and opposite, and the voltage to ground at the middle of the circuit will be zero. Aside from the length and other physical dimensions of the exposure, it is evident that the magnitude of the induced effects will depend upon whether or not both wires of the lighting circuit are present, the total voltage of the circuit, and the location of the exposed section with respect to the terminals of the lighting circuit.

If the exposure involves only one wire of the lighting circuit near either of its terminals, the induced effects are liable to be severe; if near the middle of the circuit, the effects are relatively smaller. If two sides of the circuit are present, the voltages to ground are equal and opposite provided an equal length of wire and an equal number of lamps are in each side within the exposed section and between the exposed section and the constant-current regulator. The magnitude of the harmonic voltages between the two wires depends upon the number of lamps beyond the exposed section. With such symmetrical lamp circuit layouts it is generally practicable to reduce the induced disturbances to tolerable magnitudes by means of transpositions in both lines, provided the separation is not less than the width of a highway. Since each lamp contributes to the disturbance, lamps occurring within the exposed section must be treated as discontinuities. This makes coordination difficult, particularly if the number of telephone circuits is large. Such an arrangement also makes for inflexibility in the lighting circuits, as in adding or removing lamps the symmetrical arrangement must be maintained.

Another method of coordination which is more satisfactory when conditions permit its application, is the use of a series transformer to isolate the exposed section from the remainder of the circuit. The harmonic voltages acting on the exposed section will then be only those due to the lamps on the secondary of the series transformer and dissymmetry on the primary side will not contribute to the induction. The symmetrical layout need then be applied only to the secondary side. Replacing the arc lamps on the series transformer secondary with incandescent lamps without individual transformers and equipped with film cutouts, constitutes an effective remedy.

With open-wire lines it is generally difficult, at highway separations, to reduce the noise to tolerable magnitudes unless the exposures are short. Under joint use conditions it is ordinarily impracticable to reduce the noise satisfactorily without replacing all or part of the arc lamps. It is fortunate, therefore, that the use of the a-c. arc lamp for street lighting is rapidly disappearing.

D-C. Arc Circuits

Distortion of wave-shape in d-c. arc circuits is principally due to the characteristics of the mercury arc rectifier.[4] As there are no reversals of current through the arc lamps and the changes in line current are comparatively small, changes in the resistance of the lamp arcs with change in current have a practically negligible effect in causing wave-shape distortion. The voltage and current waves set up by the rectifier contain a ripple of double the frequency of the a-c. supply with single-phase rectifiers and of six times the a-c. supply with three-phase rectifiers. Odd and even harmonic frequencies of this fundamental ripple are also present.

In order to maintain the arc, a sustaining reactance is required in the single-phase rectifier. This reactance damps out the ripple and its harmonics to a large extent. If the lighting circuit contains an appreciable length of cable between the rectifier and the open-wire section, the harmonics will be still further reduced.

Since the harmonic voltages and currents are impressed at the lighting-circuit terminals, if the lamps are distributed uniformly around the circuit, the harmonic voltages to ground at the circuit terminals will be equal and opposite and the voltage to ground will be zero at the middle of the circuit. The voltage distribution is thus the same as with the a-c. arc circuit.

The discussion given above in connection with the a-c. arc curcuit of symmetrical layouts and two-wire circuits within exposures applies also to the d-c. arc

3. Tobey and Walbridge "Stanley Alternate Arc Dynamo," Trans. A. I. E. E., 1890, Vol. VII, p. 367.

4. Steinmetz: "Transient Phenomena and Oscillations," pages 264 and 265.

circuit, except that the series transformer cannot be used and that symmetry must therefore extend through the whole circuit.

While the wave-shape distortion in these circuits is less serious than in a-c. arc circuits, coordination is very difficult when the exposures are severe, as when open-wire lines are joint.

A-C. Circuits with Straight Series Incandescent Lamps

If it were not for the distortion in lamps and associated equipment the wave-shape of any series a-c. circuit, regulated for constant current, would be better than that of the constant potential source from which it is supplied. This is due to the reactance of the constant current regulator which interposes a high impedance to the harmonics in the constant-potential supply. With straight series incandescent lamps this condition is substantially realized. While the resistance of the filaments changes with the temperature and thus with the current, the changes within a cycle are very small and the resulting distortion is negligible. A number of instances have been noted[5] where the telephone interference factors of the voltage waves of such circuits were from one-fourth to one-half the factors of the constant-potential supply sources.

Unless rather severe exposures with single-wire lighting circuits are involved or the telephone interference factor of the constant-potential supply is very high, induction into telephone circuits from circuits of this type is small. Where induction does exist it is usually practicable, by revising the circuit layout as discussed in connection with the a-c. arc circuit, to reduce the voltage to ground. Obviously the departure from symmetry of layout can be much greater for a given exposure than for either type of arc circuit.

A-C. Circuits with Incandescent Lamps Individually Equipped with Series Transformers, Auto-transformers or Bridged Reactance Coils

Under normal conditions, with all lamps in service, this type of circuit, from the induction standpoint, is practically the equivalent of the straight series circuit discussed above. Harmonic exciting currents required for either the individual transformers, auto-transformers or bridged reactance coils are largely supplied by the local circuits through the lamp filaments. Important wave-shape distortion in this type of circuit occurs only when the secondary circuit of the individual transformer opens due to failure of the lamp filament. When the secondary circuit opens, the full line current becomes exciting current in the primary, greatly over-exciting the core. Because of the high impedance of the series circuit including the reactance of the constant-current regulator, the line current remains approximately sinusoidal. Practically the full amount of the harmonic voltage generated by the individual transformer appears across the terminals of the constant-current regulator.

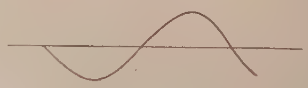

Fig. 1—Current in Transformer Primary 6.6 Amperes

Figs. 1, 2 and 3 show tracings of the voltage and current waves of one of these individual auto-transformers. Fig. 1 shows the line current in the primary

Fig. 2—Voltage Across Primary with Rated Lamp in Secondary

winding at its normal value of 6.6 amperes, Fig. 2 the primary voltage with the secondary closed through its normal lamp load, and Fig. 3 the primary voltage with

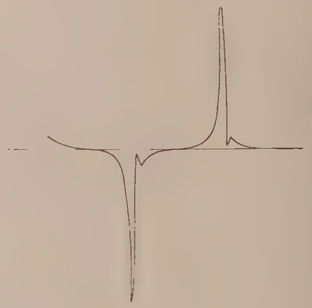

Fig. 3—Voltage Across Primary with Lamp Out

the secondary open. Following is an approximate analysis made by the 36-ordinate method of the voltage wave shown in Fig. 3.

Order of Harmonic	Frequency Cycles per Second	Volts Effective
1	60	57
3	180	40
5	300	34
7	420	31
9	540	28
11	660	26
13	780	22
15	900	19
17	1020	16
19	1140	13
21	1260	10
23	1380	8
25	1500	6
27	1620	4
29	1740	3
31	1860	2
33	1980	2
35	2100	1

In the following tabulation is given the analysis of the voltage wave at the lighting-circuit terminals and

5. Osborne "Wave-Shape Standard," Trans. A. I. E. E., Vol. XXXVIII, p. 261, 1919.

the corresponding telephone interference factors with all lamps in service and with one lamp out:

Order of Harmonic	Frequency Cycles Per Second	Volts Effective	
		All Lamps in	One Lamp Out
1	60	1380	1380
3	180	60	78
5	300	29	31
7	420	2.3	36
9	540	0.7	36
11	660	2.0	34
13	780	*	33
15	900	*	27
17	1020	*	29
19	1140	*	18
21	1260	*	20
23	1380	*	20
25	1500	*	20
27	1620	*	18
29	1740	*	16
31	1860	*	13
33	1980	*	13
35	2100	*	12
37	2220	*	10
39	2340	*	9
41	2460	*	8
43	2580	*	7
T. I. F.		13.6	447

*Indicates a value of 0.5 volts or less.

The effect of the one individual transformer, with open-circuited secondary, in increasing the harmonic voltages and the telephone-interference factor of the voltage wave of the circuit, is evident. The presence of other transformers with open secondaries increases the harmonic voltages slightly less than in direct proportion. That the increase is not linear is undoubtedly due to the effect of the small harmonic charging currents and to changes in phase of the harmonic voltages along the circuit from one individual transformer to another.

In respect to the distribution of the harmonic voltages around the circuit, an important distinction is to be made between the a-c. circuit with incandescent lamps equipped with individual transformers and the two types of arc circuit discussed above. In the arc circuits, the distribution of harmonic voltage is fixed and the voltages to ground on the exposed section remain the same as long as the circuit layout is unaltered. With this incandescent lamp circuit the harmonic voltage to ground depends both upon the number of individual transformers having open secondary circuits and upon their locations.

In discussing the effects of "out-lamps" at different locations along the circuit, it is convenient to replace the transformer by an equivalent generator with terminal voltage, e, of complex wave form and equal to the harmonic voltage drop caused in the circuit by the transformer with rated line current in the primary and with the secondary open. The impedance of the constant-current regulator at the harmonic frequencies involved is high compared to the impedance of the line and of the individual transformers having closed secondary circuits. Hence, the actual circuit may be replaced by the equivalent circuit shown in Fig. 4.

In this figure, e represents the generator equivalent to the individual transformer with open secondary. The capacitances C_{1g} and C_{2g} represent the capacitances to ground of the two wires of the circuit between this individual transformer and the constant-current regulator. It is evident that the relative values of C_{1g} and C_{2g} will vary with the position of the individual

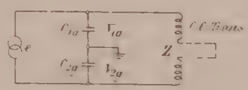

FIG. 4

transformer along the circuit, but that the sum of the two capacitances (the total capacitance to ground of the circuit) will be a constant. Letting V_{1g} indicate the voltage to ground of the section of wire having the capacitance C_{1g}; and V_{2g}, the voltage to ground of the section having the capacitance C_{2g},

$$V_{1g} = e \frac{C_{2g}}{C_{1g} + C_{2g}}$$

$$V_{2g} = - e \frac{C_{1g}}{C_{1g} + C_{2g}}$$

$$V_{1g} - V_{2g} = e$$

$$V_{1g} + V_{2g} = e \frac{C_{2g} - C_{1g}}{C_{1g} + C_{2g}}$$

If the construction of the lighting circuit is uniform, the capacitances to ground will be directly proportional to, and the voltages to ground inversely proportional to the respective lengths of wire on the two sides of the individual transformer with open secondary.

As an example illustrating the effect of the relative positions of the constant-current regulator, the individual transformer with open-secondary circuit and the exposure section, consider the arrangement shown in

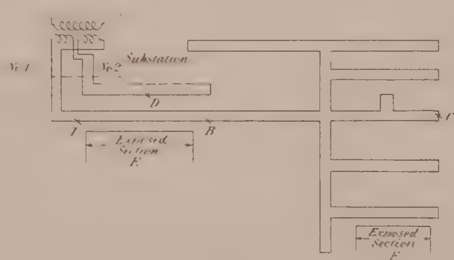

FIG. 5

Fig. 5. This includes a constant-current transformer with double secondary feeding two lighting circuits. It is assumed that the circuits are two-wire throughout their whole length and that the wire arrangements in the two exposed sections are identical.

If a lamp fails at D or at any point along the circuit (No. 2) not involved in the exposure, the harmonic

voltages impressed on circuit No. 1 will be relatively small due to the high impedance of the constant current transformer. The effects in causing noise in either exposure indicated will be correspondingly small. If a lamp fails at A, the wire on one side of the individual transformer with open secondary will be a small fraction of the total length of the circuit, while the other wire will be nearly equal to the total length. The voltages to ground on the wire involved in either exposure and the corresponding noise effects will then be relatively low, the wire having the high voltage to ground not being within the exposures.

If a lamp fails at B, one of the wires involved in the exposure section E will have a relatively large harmonic voltage to ground and the other a relatively low voltage, while both wires in section F will have the relatively low voltage to ground. Thus, considerable noise may be caused in telephone circuits involved in the exposed section E, but relatively little in section F.

C indicates a lamp at the middle of the circuit. In case of lamp failure at C, equal and opposite harmonic voltages to ground will be caused on the two wires. The voltages to ground within exposure E will then be approximately balanced. The voltage between the wires will be equal to the full harmonic voltage caused by the individual transformer. If the circuits in this section are in close proximity, as on a joint line, the noise effects are apt to be as severe as when the lamp failure occurs at the point marked B, especially if the two wires of the lighting circuit are at opposite ends of the crossarm. With the lines separated by the width of the highway, the noise effects will be much less than with an outage at B.

In exposure section F, when the outage occurs at C, the two wires of the lighting circuit will have equal voltages to ground both in magnitude and in phase, and each equal to one-half of the total harmonic voltage generated by the individual transformer. Under these conditions, the noise effects are apt to be severe whether the lighting and telephone circuits are on the same or opposite sides of the highway.

It will be evident from the preceding discussion that it is impracticable to obtain adequate relief from induction merely by symmetrical arrangements of the lighting circuits. While such an arrangement might be effective for one location of the out-lamp, it might be quite ineffective for some other location. More practicable methods involve the use of group series transformers in combination with circuit rearrangements.

Since the harmonic voltage drop along the lighting circuit is small, the harmonic voltage across the terminals of a series transformer supplying a group of individual transformers, and the voltage to ground on the secondary, are small when lamp failures occur at points other than on the secondary of the series transformer. When a failure occurs, opening the secondary circuit of one of the individual transformers in the group supplied by the series transformer, the harmonic voltages to ground along the secondary circuit of the series transformer, are distributed as though the series transformer were replaced by the constant-current regulator. Similarly, the distribution of harmonic voltage along the main lighting circuit is as though the series transformer were replaced by the individual transformer having the open secondary circuit. Thus, when a number of groups of individual lamp transformers is supplied by series transformers, lamp failures cause an important effect only on the secondary of the particular series transformer in which the outage occurs and on the main circuit and not on the secondaries of the other group-series transformers. If the telephone exposures involve only the secondary sides of the group series transformers, the number of lamps which may cause noise due to outage will be much less than if all individual transformers were directly in series with the main circuit. Thus, a large reduction in noise interference due to lamp outage may often be obtained by rearrangement of the lighting circuit so that the sections involved in telephone exposures are secondary circuits of series transformers supplying a limited number of individual lamp transformers.

Failure of a lamp on the particular secondary loop involved in the exposure will introduce the harmonic voltages on this section of circuit. If the lighting and telephone circuits are on joint lines, or if there is but a single lighting-circuit wire present at highway or closer separations, the noise effects may be very severe when a lamp fails on the section involved. With two-wire lighting circuits at highway separations having a comparatively small number of lamps the noise effects due to one lamp being out will usually be much less than a similar lamp failure on a circuit having a comparatively large number of lamps. This is due chiefly to the shorter length of the circuit having a limited number of lamps as compared to one of a large number. When a failure occurs on one of these shorter circuits at such a point that the voltage to ground on one side of the individual transformer with open secondary is large, as compared to that on the other, the length having the higher voltage will be so short as not to constitute a very serious exposure. If the failure occurs at a point on the circuit, so that the exposed section is between the series transformer supplying the circuit and the individual transformer with open secondary, the lengths of wire on the two sides of this individual transformer will be nearly equal, and therefore, nearly equal and opposite voltages to ground will be set up on the two wires within the exposed section.

Similar results may be obtained by the use of small pole-type constant-current regulators, controlled by time-clocks or by series relays in another lighting circuit (the so-called cascade arrangement). As compared to the circuit supplying a number of group series transformers, distortion of wave-shape on a main series circuit is avoided. This facilitates coordination in many cases as it is often difficult to avoid exposures

with the main series circuit when the group series transformers are employed. Failure of lamps on the individual circuits will affect only the wave-shape of the circuit upon which they occur.

Effects of out lamps on the individual circuits where supplied by group series transformers or separate regulators may be avoided by replacing the lamps on the circuits involved in the exposures with *straight* series lamps without individual transformers.

It is very difficult to obtain satisfactory conditions from the standpoint of induction from this type of circuit by lamp maintenance alone. A very high degree of maintenance is required, necessitating careful and frequent inspections and prompt replacements of the failed lamps. On circuits containing 100 lamps each, an average outage of only one per cent corresponds to one lamp out on each circuit which as already shown may cause considerable noise in exposed telephone circuits. In some instances, where less careful maintenance routines have been followed, an average outage of between three and four per cent has been noted, resulting in severe noise conditions in exposed telephone circuits.

As an aid to obtaining a very high degree of maintenance, a device known as an "Out Lamp Indicator" has been developed. The device consists of a filter in combination with a milliammeter which is connected to the secondary of a potential transformer, the primary of which is connected across the line terminals. The filter cuts off from the meter substantially all current of fundamental frequency, but permits the transmission of the higher harmonics which are generated by an individual transformer with open secondary circuit. The magnitude of the reading obtained with one lamp out depends upon the rating of the individual transformer and the ratio of the potential transformer. In order to avoid an excessive fundamental frequency voltage on the network and saturation effects on the potential transformer, it is necessary to limit the secondary voltage to approximately 120 volts. Readable deflections with one individual transformer with open secondary circuit may be obtained with potential transformer ratios up to 50 to 1.

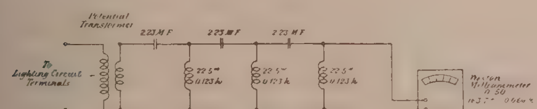

Fig. 6

A diagram of the filter with constants of the elements is given in Fig. 6. Fig. 7 shows a frequency response curve of the combination, indicating the milliamperes in the meter, per volt at the potential transformer secondary terminals at various frequencies.

In employing this device in maintaining the circuits, readings are taken on the lighting circuits indicating whether or not lamps are out and how many. The circuits may then be patrolled and the out lamps replaced. Experience has indicated that lamps near the end of their life fail immediately after a surge such as when the circuit is deenergized or when energized after having been out of service. If readings are taken

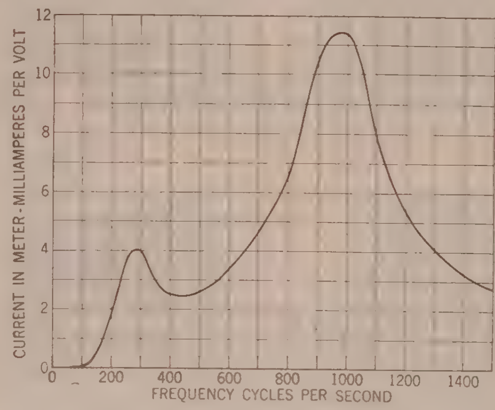

Fig. 7—Frequency Response Curve of out Lamp Indicator Milliamperes in Meter per Volt at Secondary Terminals of Potential Transformer

shortly after the circuits are energized and the out lamps replaced, all lamps are likely to remain in service for the rest of the night. If indications are not obtained on a given circuit, patrolling is, of course, not necessary. Where a circuit is made up partly of straight series lamps with film cutouts and partly of individual-transformer type lamps, no indication will be obtained of an outage of one of the straight series lamps.

Another valuable aid to maintenance is the practise followed by one large company of replacing lamps at definite intervals less than full life in connection with the cleaning schedule. The replaced lamps are then submitted to a photometer test and if not up to standard are destroyed. The lamps indicating additional useful life are then reinstalled in circuits that are not involved in exposures with telephone circuits. This method, in conjunction with the use of the out-lamp indicator, has, except for an occasional outage, eliminated inductive trouble from these circuits.

While great improvement may be effected in many cases by the application of the measures discussed above, the most direct and fundamental remedy for noise interference from this type of circuit would be the provision on each fixture of a device which would short-circuit the individual transformer when the associated lamp fails. However, unless such a device can be secured at a cost which would not sacrifice the economies obtainable by the use of the high-current lamps with the individual transformers, it would become cheaper to place the lamps directly in the series circuit omitting the individual transformer. Due to saturation of the individual transformer, only a small increase in the effective voltage across the secondary takes

place, a much larger increase occurring in the value of the peak voltage. Some device whose operation depends upon the peak voltage seems most promising and least likely to be subject to false operation due to surges.

Conclusion

Close cooperation between the power and telephone utilities, as in all matters involving the relations between these utilities, is needed to prevent or overcome interference from lighting circuits, particularly in planning extensions or new construction. It is hoped that the information given in this paper will prove useful to power and telephone engineers in their cooperative efforts to solve these difficulties.

The Klydonograph and Its Application to Surge Investigation

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Synopsis.—In the past few years the need of a device for recording voltage surges on transmission lines has been felt more and more. Realizing this need J. F. Peters, in the fall of nineteen twenty-three, developed the klydonograph which utilizes the Litchtenberg figure to record the characteristics of transient voltages. The principle of the instrument and practical connections to a line are discussed. The results obtained in the field from four investigations are given.

Parts II and IV describe the first experimental model of the klydonograph which uses a stationary glass photographic plate in removable plateholders with a moving electrode, and the commercial type of klydonograph which uses a daylight-loading roll film, of sufficient length to last seven days. This latter model has three electrodes for connection to a three-phase line.

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1. Principle and Characteristics

SINCE the beginning of high voltage transmission the question of the nature of transient voltages on transmission systems has been a troublesome problem. There is considerable evidence that transient over voltages of short duration do exist on transmission lines and information regarding them is very desirable. There has been developed a considerable amount of theory regarding these transients but very little verification of this theory by test has been produced, due to the absence of a satisfactory means of measurement. Heretofore, the spark gap has been the principal means of measurement. It was found that the spark gap had considerable time lag when the voltage in excess of its flashover value was small. Other objections to the spark gap for the measurement of transients are well known. Various other devices that have been tried had practically the same objections; that is, they had time lag, were not graphic, indicated only one value, introduced hazards to the line or were excessively expensive.

Principle. The klydonograph[2] is a satisfactory surge recorder, giving a continuous graphic record of detailed information regarding magnitude, time of day, polarity, steepness of wave front, direction of travel and whether or not the surge was oscillatory. In producing this instrument, a phenomenon was utilized that has been known for a century and a half. In 1777, Dr. G. C. Lichtenberg first observed that when a condenser was discharged onto a terminal in contact with a plate of insulating material, such as ebonite, between it and a grounded metallic plate and particular kinds of powder, such as flour of sulphur, were sprinkled on the insulating plate, the powder would arrange itself about the position of the terminal in a distinctive and consistent manner. The powder could be applied either before or after the discharge. Figures thus formed are called Lichtenberg figures.

Since the original observations, there has followed a long series of investigations on these figures. In 1888, J. Brown and E. Trouvelot discovered that these figures could be produced by replacing the insulating plate with a photographic plate, the emulsion being in contact with the terminal. The plate, of course, had to be kept in a dark box. The glass plate acted as the insulating material and the emulsion, when developed, replaced the dust. The most recent and most complete exposition of the Lichtenberg figures was that by P. O. Pederson of Copenhagen, Denmark, in a paper for "Det. Kgl. Danske Videnskabernes Selskab, 1919."

The essential elements of the klydonograph are shown in Fig. 1. The form in which these were assembled for the laboratory work is shown in Fig. 2. For this work, it was found that any plate of high

1. Both of the Westinghouse Electric & Mfg. Co.

2. The word "Klydonograph" was suggested by Dr. Roscoe M. Ihrig of the Carnegie Institute of Technology. It is derived from two Greek words "Kludon" and "Graphos." Kludon means "billow" or "wave," and a related adjective means "surging" or "dashing." Graphos means a writing. Thus the Klydonograph means an instrument for recording surges.

The Klydonograph, J. F. Peters, *Electrical World*, April 19, 1924.

Abridgment of paper presented at the Annual Convention of the A. I. E. E., Saratoga Springs, June 22-26, 1925. Complete copies to members on request.

photographic speed was satisfactory. No work was done using dust figures.

Characteristics. When a voltage above the critical voltage is impressed between A and B of Fig. 1, and the plate developed, a figure will be found surrounding the

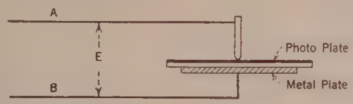

FIG. 1—ELEMENTS OF THE KLYDONOGRAPH

spot where the terminal has been in contact. The critical voltage is approximately 2.0 kv., below which, at atmospheric pressure, no figure is produced. The figures consist of branches, or lines, emanating uniformly from the center. They maintain this form up to about 18 kv., when, in addition to the uniform

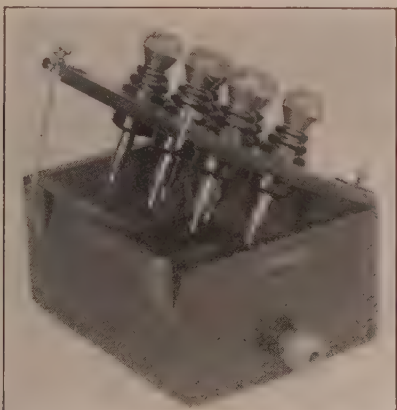

FIG. 2—LABORATORY KLYDONOGRAPH

branches, main trunks extend out from the center and, in turn, act as emission points for other branches. These trunks do not form in a consistent manner as do the branches. If the voltage is further increased, a point will be reached where a visible spark will occur

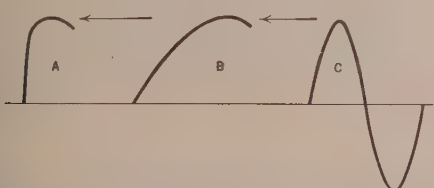

FIG. 3—TYPICAL WAVES: (a) ABRUPT, (b) SLOPING, (c) ALTERNATING

and the entire plate will become exposed. If the voltage impressed is unidirectional there will be a striking difference between the figures produced by positive and negative potentials. In the case of an oscillating voltage the two will be superimposed. By the figures one may also distinguish between an abrupt-front surge, such as indicated in Fig. 3A, and a tapered-front surge, as indicated in Fig. 3B. Figs. 4 an 5 show a positive and a negative surge, respectively, having a front as

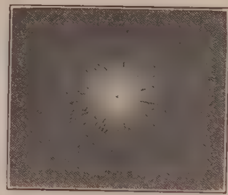

FIG. 4—POSITIVE SURGE, ABRUPT FRONT

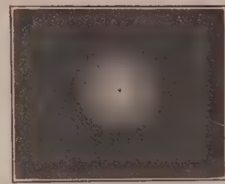

FIG. 5—NEGATIVE SURGE, ABRUPT FRONT

FIG. 6—POSITIVE SURGE, FIVE-MICROSECOND FRONT

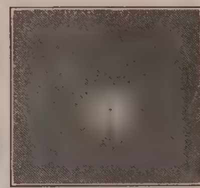

FIG. 7—NEGATIVE SURGE, FIVE-MICROSECOND FRONT

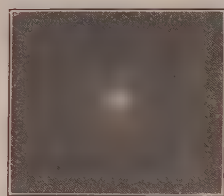

FIG. 8—POSITIVE SURGE, 200-MICROSECOND FRONT

FIG. 9—NEGATIVE SURGE, 200-MICROSECOND FRONT

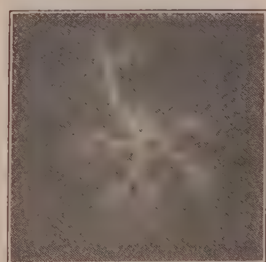

FIG. 10—POSITIVE SURGE, ABOVE RANGE OF INSTRUMENT

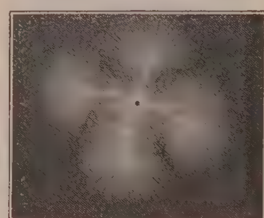

FIG. 11—NEGATIVE SURGE, ABOVE RANGE OF INSTRUMENT

FIG. 12—ALTERNATING VOLTAGE

abrupt as could be produced by ordinary means in the laboratory. Figs. 6 and 7 show a positive and a nega-

tive surge, respectively, having a front of five microseconds; that is, it required five-millionths of a second to rise from zero to its maximum value. This corresponds to a traveling wave having a front of one mile on a transmission line. Figs. 8 and 9 show similar surges having fronts of 200 microseconds or 40 miles. Distinct differences in the figures formed by these three lengths of wave front can be noticed. Figs. 10 and 11 show a positive and a negative surge that were above the range of the instrument. Fig. 12 shows a figure produced by an alternating potential such as in Fig. 3c.

Tests were made to determine whether or not one application affected the plate in succeeding applications. Tests were made which proved that one impression has no effect on succeeding records. If two surges are impressed simultaneously on adjacent terminals the figures

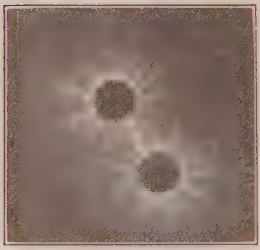

Fig. 13—Positive Figures, 30 Seconds Between Surges

Fig. 14—Negative Figures, 30 Seconds Between Surges

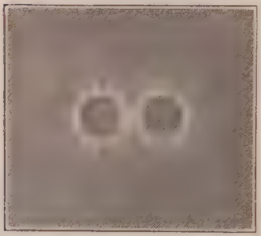

Fig. 15—Positive Figures, Terminal Moved Between Surges

Fig. 16—Negative Figures, Terminal Moved Between Surges

will not overlap. If a surge is applied on the positon of a previous surge it superimposes its figure exactly as if there had been no previous figure and the rays of the two figures cross each other promiscuously. Figs. 13 and 14 show positive and negative surges, respectively, where one surge was impressed and a few seconds later a surge was impressed on the adjacent terminal. Figs. 15 and 16 show similar surges where there was a similar interval and each terminal was in contact with the plate only when the surge was impressed. Further, the size of each succeeding figure was determined only by the applied voltage. This was checked by applying surges of equal values a various number of times, one to six, on the six terminals of the instrument. The figures were of the same size and differed only in intensity.

Calibration. Fig. 17 shows the network used in the laboratory as a surge generator in the development of the klydonograph. Fig. 18 shows the shape of a typical surge as calculated from the constants of the network. By varying the constants of the network a surge of any desired wave shape could be produced. To obtain the desired setting the klydonograph was removed and

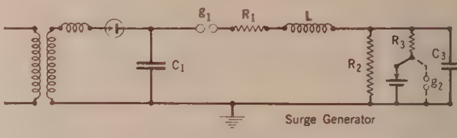

Fig. 17—Network Used in Laboratory

gap g_2 inserted and set at the desired voltage. Gap g_1 was then varied until g_2 would just spark-over at the breakdown of g_1. Gap g_2 was then replaced by the klydonograph and leaving g_1 as set, a series of figures were made.

The diameter of the figure is a measure of the magnitude of the surge. Positive and negative surges have quite different calibrations, a positive figure being considerably larger for the same voltage. Since the positive is the larger, the a-c. calibration is the same as the positive. All the work for the calibration curves was done with five microsecond and 200 microsecond surges. Tests were made which indicated that for a surge with a front as long as 5 microseconds the time lag of the measuring sphere-gap was negligible. In addition to this, the characteristics of the surge generator used gave a surge with a comparatively flat top. It was found that the calibration was the same for unidirectional surges of both these wave fronts of each polarity as well as for a 60-cycle and a 25-cycle a-c. wave. The figures shown as abrupt-front surges were as abrupt as could be made with ordinary methods.

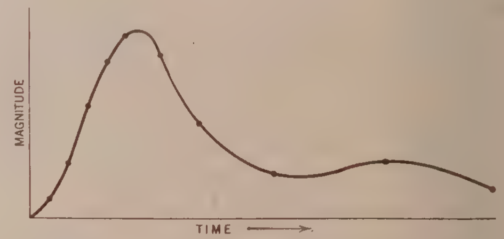

Fig. 18—Typical Surge Produced by Network of Fig. 17

It takes a certain time for a sphere-gap to break down and become highly conductive so it was felt that surges thus produced could not be called absolutely abrupt nor be depended upon to be of the same degree of steepness. They were, therefore, not used in calibration work.

It was found in calibrating that the radius of a figure made at a setting of the generator would vary as much as 20 per cent from the average reading of the same value but most of them were within 10 per cent of the

average. This would not seem to be very accurate at first glance, but it is maintained that the variation was in the voltage impressed, due to inaccurate setting of the spark-gap and inaccuracies in the method used, and not in the figure made by the klydonograph at a given voltage. The network would be set for a given voltage and condition of surge. The voltage was tested in the position of the klydonograph by a sphere-gap. A series of pictures would then be taken and the network changed to some other value. The curves were made

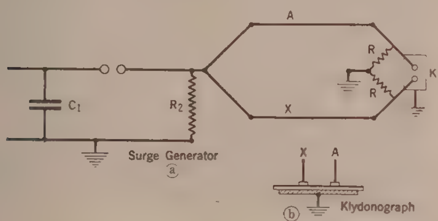

FIG. 19—ARRANGEMENT USED TO MEASURE SHORT-TIME INTERVALS
(a) SURGE GENERATOR (b) TWO-TERMINAL KLYDONOGRAPH

up from the results of a great many settings for a given value. These settings were made on different days, over months, and it is impossible to duplicate such a set up with exactness. The basis for attributing the error to set up rather than kyldonograph is the fact that for a single setting the variation between the figures was exceedingly small. To test this quality further, surges were thrown on six leads connected to the six terminals of the test instrument, simultaneously, and in practically every case there were no variations that could be

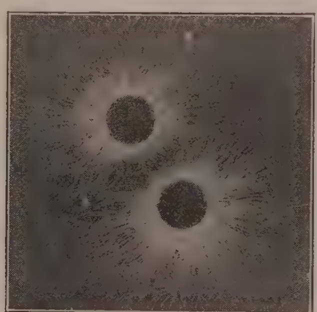

FIG. 20—POSITIVE FIGURES IMPRESSED OVER EQUAL LINES
$A = X$

measured. In the few cases where there were measurable variations, these variations were very slight.

Rapidity. Since surges may be of extremely short duration it was highly important that the klydonograph be a rapid instrument. Many tests were made to determine the speed of formation of the figures. The diagram of the set up used to obtain these data is shown in Fig. 19. This merely consisted of a circuit which discharged a condenser through a sphere-gap into two open-wire lines which were shunted to ground by a high resistance. The lines A and X were connected at the far end to a special klydonograph having two ⅜-in. terminals in contact with the plate at a short distance apart. The time lag of the sphere-gap used to discharge the condenser played no part as the data obtained was of conditions after the gap had broken down. When the sphere-gap broke down a surge was impressed on the two lines simultaneously and would proceed as a traveling wave at approximately the speed of light. If the lines were of equal length, the wave would arrive at the ends at the same time. Figs. 20 and 21 show positive and negative figures, respectively, made with equal length lines. Tests were

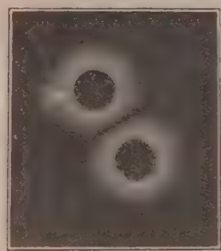

FIG. 21—NEGATIVE FIGURES IMPRESSED OVER EQUAL LINES
$A = X$

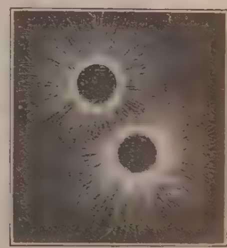

FIG. 22—POSITIVE FIGURES IMPRESSED OVER UNEQUAL LINES
$A = 30$ $X = 50$

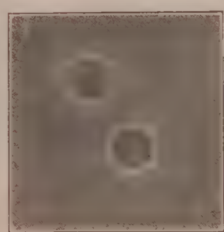

FIG. 23—POSITIVE FIGURES IMPRESSED OVER UNEQUAL LINES
$A = 50$ $X = 140$

FIG. 24—NEGATIVE FIGURES IMPRESSED OVER UNEQUAL LINES
$A = 30$ $X = 60$

then made having one line longer than the other. Figs. 22, 23 and 24 show surges impressed on unequal lines. Fig. 22 is for a positive surge with $A = 30$ ft., and $X = 50$ ft. From the rate of propagation of a surge on an aerial line this difference of 20 ft. represents a time interval of 2 by 10^{-8} or twenty billionths of a second. It is to be noticed that the surge from the shorter line took possession of more than one-half the space between the figures. Fig. 23 is for a positive surge with $A = 50$ ft., and $X = 140$ ft. This difference of 90 ft. corresponded to a difference in time of the arrival of the wave at the instrument of 9 by 10^{-8} seconds or ninety billionths of a second. It is noted here that A is practically fully developed when the wave arrived at X, so that the figure became nearly complete in ninety billionths of a second. Fig. 24 is for a negative surge with $A = 30$ ft., $X = 60$ ft. The negative figures were

found to be the slower by about five times. This is evident from a comparison of Figs. 22 and 24. However, either is amply rapid for the purpose of recording practical surges.

Electrostatic Potentiometer. To be applicable to transmission systems in general the instrument must have a wide range of voltage. The range of the instrument itself is from 2.5 kv. to 18 kv. Since the instrument is an exceedingly low current device, it can be connected by means of an electrostatic potentiometer to lines of practically any voltage without introducing an insulation hazard. An electromagnetic multiplier is,

Fig. 26—Figure Produced by Synchronous Klydonograph

of course, out of the question since there must be no time lag. Fig. 27 shows a satisfactory method of connecting the klydonograph to a line. The lower ring in this set-up will maintain at all times the same proportion of the potential on the upper ring. A klydonograph connected in this manner will record figures giving the magnitude and polarity of the surges.

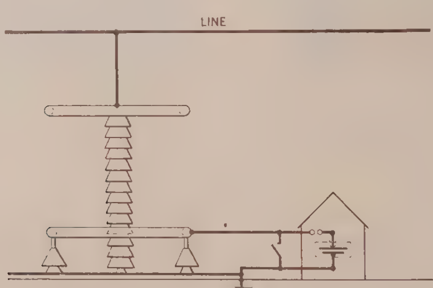

Fig. 27—Diagram of Electrostatic Potentiometer

A gap in series with the instrument may be included as shown, or left out as desired. If included there will be no record except, in case of a surge, the voltage of which is in the same ratio to normal as the setting of the gap is to the normal voltage on the lower ring. If no gap is used, there will be a uniform band on the plate corresponding in width to the diameter of the positive figure at the normal voltage on the lower ring.

Antenna. Fig. 28 shows a means of connection that will give the steepness of wave front. This consists of running a wire parallel to the transmission-line conductors, grounding one end solidly and the other end, through a high impedance. The klydonograph is connected across this impedance and if the impedance is high compared to the impedance of the antenna loop, itself, the klydonograph will measure any voltage above 2.5 kv. which may be induced in the loop. This antenna

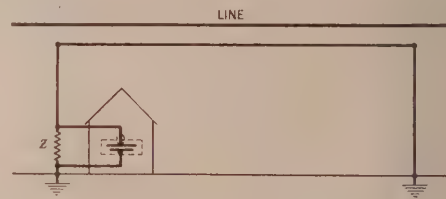

Fig. 28—Diagram on Antenna

loop will have a certain mutual inductance in relation to the various conductors of the transmission line. The voltage induced in the antenna loop will be proportional to $d\,i/d\,t$ on the transmission line; that is, it is proportional to the steepness of the current wave. Under traveling wave conditions the current is always equal to the voltage divided by the surge impedance of the line and the wave shape is the same.

By a comparison of the polarity of simultaneous readings on the klydonograph connected to the line through the electrostatic potentiometers and that connected on the antenna, the direction of travel can be determined; that is, a surge of a particular polarity will induce a potential of one polarity in the antenna

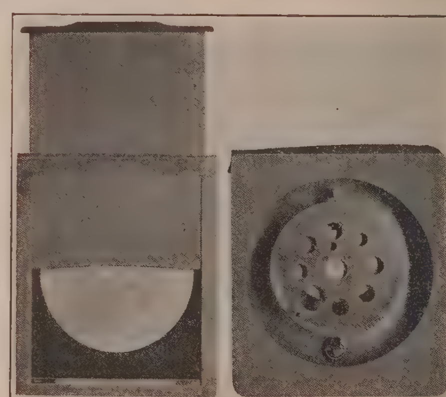

Fig. 29—Plate-Type Klydonograph, Showing Rotating Electrode and Hour Circle

if traveling in one direction and of the opposite polarity if traveling in the other direction. The direction is readily determined from an examination of the connections. Thus, magnitude and polarity are obtained directly from the potentiometer klydonographs, steepness of wave front from the antenna klydonograph and the direction of travel from a comparison of the polarity of the two.

II. Preliminary Field Model, Plate Type

The first field model, Fig. 29, was made with a *stationary plate* in a removable holder, enclosed within the same light-tight cabinet with the clock-driven electrode.

A one-day clock was used in most recorders, driving

Fig. 30—30-Kv. Electrostatic Potentiometer

the electrode in a 7-in. circle, one revolution in 24 hours. The electrode was mounted vertically near the edge of a light disk of insulating material, having a wire-collector

Fig. 31—140-Kv. Electrostatic Potentiometer

ring on its periphery. The lead-in terminal, passing through an insulating bushing in the case, had a brush on the bottom end which bore on the collector and thus

Fig. 32—220-Kv. Electrostatic Potentiometer

carried the potential to be measured to the electrode proper. This electrode was free to move up and down and pressed on the sensitive side of the photographic plate with its own weight only.

In order that the time at which each surge occurred might be known by a glance at the finished photographic plate, a photographic template was prepared with opaque background and transparent dial and figures. All klydonograph plates were exposed to light with this template over them, so that when the plate was developed, a circular scale marked in 24 hours with "Midnight" at top and "Noon" at bottom, appeared. An hour circle on the electrode disk was set correctly before starting the test.

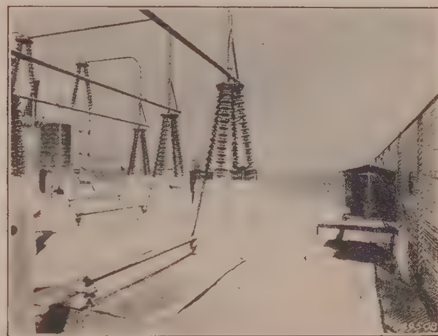

Fig. 33—220-Kv. Bus Type Potentiometer

The instrument was inverted to set the electrode disk through a large hole in bottom of the case and before turning the instrument right side up, the plate holder was inserted. The removal of the rubber slide from the plate holder permitted the electrode to drop to the sensitive surface of the photographic plate, and thus be in condition to take a klydonogram. After a 24-hour test, the instrument was again inverted, the rubber slide replaced and the plate holder removed.

III. Field Experience

Since the film-type instrument has only now been made available, all the field work has been done

Fig. 34—Section of Plate Without Series Gap. Oscillatory Surge

using the moving electrode, plate-type of klydonograph.

Potentiometers. Fig. 30 shows the potentiometer rings which were used on the 26,400-volt system. It was found that a 30-in. ring of 2-in. iron pipe, mounted as shown, was satisfactory on this class of voltage. The high potential element was mounted about 30-in. above the ground plate. The lower ring was placed at such a height that it had a potential of 3-kv. crest

with normal voltage on the upper ring. Six to eight foot rings were used on the higher voltage lines. Fig. 31 shows the set up used on the 140-kv. line and Fig. 32 shows the set up used on the 220-kv. line. The height of the upper ring was between 8 and 12 ft. from the ground plate, and the lower ring as before, to give 3-kv. crest with normal voltage on the upper ring.

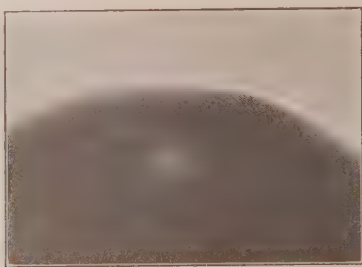

Fig. 35—Section of Plate with Series Gap. Positive Surge

In order to make the position of the ground beneath the rings constant, the rings were mounted on a metallic sheet consisting of either sheet iron or closely woven mesh. This ground plate was made large enough to extend about a foot beyond the outside circumference of the rings and solidly grounded.

An alternate form of potentiometer, shown in Fig. 33, was found feasible on the 220-kv. test and was used at three of the stations.

The potentiometers were calibrated by measuring the voltage on the lower ring with a 5/8-in. sphere-gap with normal voltage on the upper ring. With the potentiometer set to give 3-kv. crest with normal line voltage, the upper limit of the instrument, or 18-kv. crest, permits the measurement of a surge of six times normal voltage and the recording of a surge eight times normal before the instrument will spark-over.

Antenna. It was found that where the transmission line had a ground wire, this was generally in sufficiently close proximity to the line to act as an antenna. By insulating the wire on one tower, extending it down and grounding it through a suitable resistance, the antenna loop was complete. This could be made as long as desired by insulating the wire from as many towers adjacent to the end tower as necessary. Fig. 36 shows an antenna set up effected in this way. On lines where no ground wire was used, it was a simple matter to mount a wire on the transmission line poles or towers.

Tests and Results. While up to the present writing, there has not been time for as much field experience as could be desired, rather extensive tests have been made on four systems representing a wide range of conditions of electric power transmission.

a. These tests were made on a 26,400-volt system consisting of connected cable and open wire. Grounding was varied between solid and 150-ohm resistance. One instrument was installed on one-phase at a substation having cables extending in each direction and another instrument on the same phase on the open wire line, 18 miles from the junction of cable to open-wire. The tests were continued 20 days.

During this 20-day investigation 18 surges were recorded. The largest number in one day was three. All were obtained on the instrument on the open-wire line. Of these surges, two were twice normal voltage, six were 1.5 times normal and ten were 1.3 times normal or less. As to weather conditions, eight occurred in clear weather, seven during rain, two in cloudy weather and one during an electric storm. Both surges twice normal came during rain and wind. As to attendant causes; the two surges twice normal were not caused by a switch operation but switches were tripped by the disturbances. The one surge during an electric storm was 1.3 times normal. Of the total, nine were caused by switching and one by lightning. No cause could be assigned to the remainder, of which three came in clear weather and five during rain.

b. These tests were made on a 27,400-volt cable system. Only one instrument was installed at a pot head of a station with cables extending in both directions. The system was solidly grounded at one point approximately 10 mi. from the klydonograph. The duration of the test was 104 days.

During this investigation, 24 surges were recorded. One was 1.5 times normal, one was 1.4 times normal and 22 were 1.3 times normal or less. Nine occurred in rain and 15 on clear days. The probable cause of the surge 1.5 times normal was a switch operation within three miles of the instrument. The 1.4 times normal surge occurred during switching operations.

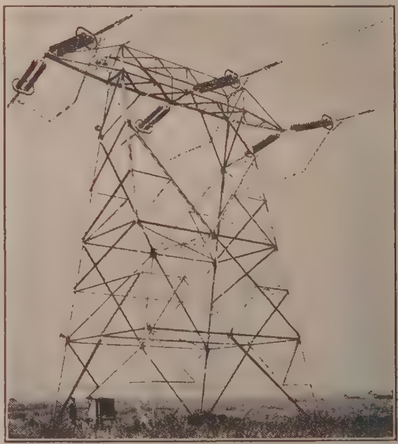

Fig. 36—Antenna Connection on 220-Kv. Line

c. These tests were made on a 240-mile, 140-kv. open-wire line with a free neutral. Three instruments, each on potentiometers, were installed at the receving end, 65.5 mi. and 193 mi. from the receiving end and at

the sending end. One antenna instrument was installed at the receiving end. The duration of these tests was 65 continuous days.

During this investigation, 124 surges were recorded on the potentiometer instruments. Of these, 22 were at the sending end, eight at the second station, 27 at the third station and 67 at the receiving end. Fifty-four of these were 1.4 times normal or above and were distributed according to Table No. I.

TABLE NO. I

Surge Magnitude times normal	Sending end	Second Station	Third Station	Receiving end
3.5 to 4.2				2
2.5 to 3.5	1		2	6
2.0 to 2.5	5	3	1	7
1.4 to 2.0	5	3	4	15

In two cases only were surges recorded at more than one station simultaneously. In both of these cases, the surge was oscillatory and the maximum values of the surges were 4.2 and 2.8 times normal, respectively. Of these 54 separate figures, 15 were alternating caused by three surges; that is, some surges occurred on more than one phase and extended to more than one station; 21 were positive, caused by 13 surges, and 18 were negative caused by 18 surges.

Lightning caused nine a-c. figures in two surges, maximum values 3.3 and 2.8 times normal. Only one of these caused figures at more than one station. Lightning caused nine positive figures, all at the receiving end, in four surges, with maximum values of 4.2, 2.5, 1.5 and 1.3 times normal. No negative figures were caused by lightning. The other surge that was recorded at more than one station, causing seven figures in all, was caused by a telephone wire falling into and grounding one phase at about the middle of the line. The maximum value of the surge was 4.2 times normal at the receiving end.

Of the 54 figures, 1.4 times normal or above, switching caused nine. None of these were over two times normal. To about 80 per cent of the 70 figures below 1.4 times normal, no cause could be assigned. The others occurred at times of switch operations.

Except for a few mild lightning storms, the weather was, in general, fair.

The steepnesses of a total of 106 surges were recorded on the antenna instrument at the receiving end. Of these, 16 were simultaneous with records of magnitude on the potentiometer instruments. The maximum was due to one of the oscillating surges caused by lightning and was 28 by 10^6-kv. per sec. or indicated a frequency of 16,000 cycles. The next largest was due to an arcing ground and indicated 24 by 10^6-kv. per sec. or 9000 cycles. The steepest front surge caused by switching had a slope of 14 by 10^6-kv. per sec. and was unidirectional. Of the six lightning surges on the potentiometer, there were four to which there were corresponding antenna records. Of the 90 antenna figures with no simultaneous figures on the potentiometers, 20 could be connected with switching operations. There was no apparent cause for the remainder.

The varying relationship between the widths of the positive and negative portions of the normal voltage band indicated that this system would pick up and maintain for several hours a static potential of one or the other polarity.

This investigation has not been completed.

d. These tests were made on a 270-mi., 220-kv., open-wire line, with neutral solidly grounded at four points along its length. Klydonographs were installed as follows: three on potentiometers at the sending end; three on potentiometers and one on an antenna at stations, 105 mi. from the sending end; 140 mi. from the sending end; at the receiving end. Tests were made on 120 days, covering 4½ months.

There was an unusual amount of system switching performed during the investigation and a resulting large number of surges were recorded. However, none of these were of alarming magnitude. The maximum surge recorded was 3.2 times normal voltage to ground. The next highest was 2.7 times normal. During the tests, there were two flashovers of line insulators, neither of which caused a higher voltage than 1.9 times normal; and this might have been caused by a switch operation within a few minutes of the flashover. The weather was fair during the investigation with no lightning.

Oscillations. There have been certain theories advanced regarding the existence of high-voltage, high-frequency oscillations on transmission systems. The above tests while not broad enough to be conclusive on all systems have indicated nothing to substantiate these theories except in the case of an arcing ground. Further, arcing grounds on a grounded-neutral high-tension line produced no high voltage oscillations, and in the case of the free neutral system, the frequency of oscillation did not exceed 16,000 cycles.

IV. Commercial Type of Roll-Film Recorder

As soon as the plate-type of recorder proved that the klydonograph was very valuable in obtaining data on surges on transmission systems, the complete design and construction of the roll-film type was undertaken.

Some of the desirable features to be incorporated in such a recorder are as follows:

1. Daylight loading and unloading
2. Independent of power for operation; hence clock-driven
3. At least three electrodes desired
4. A long record possible, hence roll film to be used
5. Time markings correct without resorting to cog-wheel drive and holes in edges of film
6. Capable of standing considerable over voltage
7. Reasonably constant in its calibration
8. Simple and reliable in operation
9. Truly portable; reasonably small and light
10. Rugged and not too expensive in construction

In order to harmonize these desirable features, a radically different design is required for this klydonograph than for any existing graphic instrument. In such instruments, the torque required to reroll the chart is constantly increasing from beginning to end, and hence must be supplied by a separate clock spring or motor. The same type of reroll was chosen for this klydonograph as was designed for the long-film attachment for the three-element, portable oscillograph.[3] This incorporated the daylight-loading feature and constant torque for driving film and reroll.

Daylight Loading Film. A 6½-in. width of roll-film was chosen as a desirable width for a good three-electrode chart. This film was obtained on a metal, flanged spool having extra deep holes in the ends to permit the introduction of steel pins to act as shafts. These special films are put up in cartons marked for the klydonograph. A film length of 8 ft. was chosen to give a one-week record with a film velocity of ½-in. per hr. Fig. 37 shows this film in place in the klydonograph. The system consists of a main clock-driven drum over which the film passes on its way under the electrodes. The outer shell of the drum is micarta insulation. Beneath this is a thin metal sheet moulded into the micarta tubing. The metal sheet is grounded, through the metal ends of the drum, to the frame. It is practically impossible to make a thin film lay flat on a glass plate and touch all parts of the surface. However, it is much easier to make a film roll over a micarta cylinder and hug the cylinder so as to have no air spaces between the film and the cylinder under the electrodes of the klydonograph. In this design, we have a repetition of the essential features of the original klydonograph. The film used in this klydonograph has

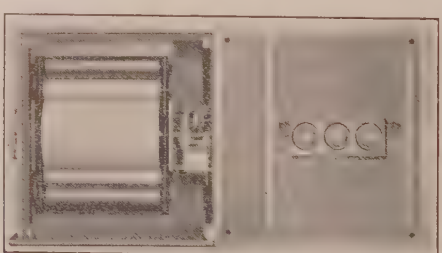

FIG. 37—THE KLYDONOGRAPH, COVER REMOVED, SHOWING FILM IN PLACE

black paper on each end but none under the film itself. This permits of daylight loading and daylight unloading without introducing an undesirable member between the film and the internally grounded drum.

Reroll Scheme. The general construction of the rerolling system can be seen in Fig. 37. On one side of the main drum is the unexposed film; on the other side is the exposed film. Beyond each of these is a roller with pulleys attached. Two helical-spring belts hold the rollers against the film cartridges, and, in turn, the cartridges against the main drum. If the under side of each belt is tight and the upper side relatively slack, the film will be drawn tight over the top half of the main drum. Now, as the main drum is turned by hand or by the clock, the unrolling action from one spool will cause a rolling-up action on the other spool by means of the rollers and the two belts. The driving pulleys are made larger than the driven pulleys so that the under side of each belt will remain tight

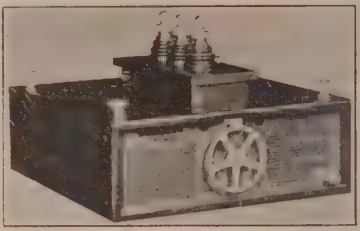

FIG. 38—FILM-TYPE KLYDONOGRAPH—GENERAL VIEW

and the upper side relatively slack. Thus the film is urged to roll up faster than it is unrolled from the first spool. The rollers and film spools are held in alinement by shaft extension, free to slide in longitudinal grooves in the metal frame.

No slipping of either film or rollers takes place, for the ratio of the pulley diameters is so chosen as to keep the twisting torque as high as possible and yet well below the point where the rollers would slip on the film. As the unexposed film-roll decreases in diameter, the exposed roll increases in diameter, and the film shafts and the roller shafts shift along in the horizontal groove. The center distance between the pulleys remains practically constant with this arrangement and hence the tension in the belts does not change. All of these novel features go to make a simple but reliable reroll system which may be driven by a single clock.

Time Marker. The clock is geared to the drum so as to drive the film at a uniform speed of approximately one foot per day. The drum actually makes just one revolution in 24 hours. By means of a stationary speck of *luminous paint,* just under one edge of the drum cylinder, and twenty-four equally distributed holes through the outer edge of the cylinder, a dot is exposed on the edge of the photographic film every hour, and a dash every sixth hour. Each hole passes over the speck of luminous paint just as that hole lines up with the three electrodes. Hence, there can be no error in time marking, even if the film should vary several inches in its travel during one week, provided the 8-day clock keeps good time.

An *hour circle* is provided on the end of the main-drum shaft on the outside of the klydonograph. This has 24 graduations, each of which lines up with an index at the same time as the corresponding hole in

3. TRANS. A. I. E. E., p. 381, Feb., 1923—Legg: Portable Oscillograph.

the edge of the cylinder lines up with the electrodes.

A *daylight intensity* record appears on the opposite edge of the film from the dots and dashes. Daylight enters the case through a horizontal hole in the upper part of the klydonograph and is reflected downward through a vertical hole in the cover to a point on the film in line with the electrodes, thus giving the record of day and night, by reference to which it is easy to determine which time-dash is 6 a. m., which 12 m., which 6 p. m., and which midnight. At any setting, daytime can be told from night, but by adjusting the amount of reflection, according to the locality and position of the klydonograph, it is possible to get a record of the variation in intensity of daylight as caused by changing cloud conditions. This last feature is not essential but is often very helpful in checking up the causes of surges which appear on the film.

Complete Instrument. The complete roll-film type of klydonograph is shown in Fig. 38. The parts which appear on the outside are, the three electrode-terminals, their lead-in bushings, the daylight-intensity adjustor, on one side of the electrode chamber, the cover thumb-nuts, the hour circle on the instruction panel and the ground-binding-post. The outfit is but 12 by 12 by 8⅜ in. over all, the case proper being but half that height. This three-electrode, seven-day recorder is no larger than the original single-electrode 24-hour plate-model. Its weight is much less than many single-element graphic meters. It is so portable that it may be taken to any desired location on a transmission system, and in fact, in some cases located up in a transmission tower. For accurate work, special

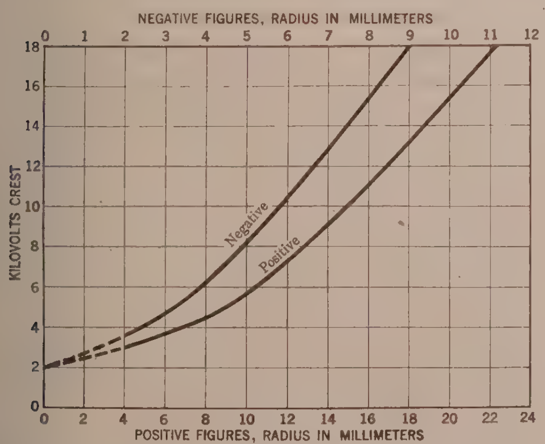

Fig. 39—Calibration of Klydonograph—Film-Type, Experimental Model

electrostatic potentiometers, previously described in this article, must be used. However, some information can often be obtained by tapping in between the first and second insulators, when of the multiple unit type, so as to lead a fraction of the voltage of each of the lines of a three-phase system to an electrode of the klydonograph.

Condensed instructions for loading and operating the instrument are moulded into the micarta panel each side of the hour-circle. No delicate mechanism of any kind is exposed and the instrument may be carried or shipped without danger of breakage.

Calibration and Tests. The calibration of this roll-film type of klydonograph proved to be very nearly the same as that for the plate type; the main difference occurring at the lowest perceptible voltages where the effect of the dielectric constant, and thickness, is most apparent. Fig. 39 shows the calibration chart of radius of figures (both positive and negative) to crest volts applied. Fig. 40 shows a short length of film with artificial surges, timing dots and dashes, and daylight-intensity record. The surge figures are described in detail in earlier parts of this article. Although the normal continuous potential on the electrodes of this instrument will be adjusted at approximately, 2500 volts, tests were made with a-c. potentials as high as 25,000 volts without damaging the instrument or puncturing the film. The calibration is not satisfactory beyond 18,000 volts, but this is 700 per cent above normal, and hence gives a very great range to the instrument. Since there is no power backing the surges as picked off an electrostatic potentiometer, and since the instrument stood higher voltages, backed with power, than can be met in practise, it is undoubtedly safe for the service intended.

Fig. 40—Section of Typical Film. Artificial Surges Produced in Laboratory

THE WORLD'S LONGEST TELEPHONE CABLE

Within the next month, the world's longest telephone cable, connecting New York and Chicago, will go into service. It is 861 miles long and for 717 miles of its length it is carried above ground on some 36,000 poles. For the remaining 144 miles this cable runs underground. Construction of the cable began seven years ago and when put into service it will provide 250 channels for telephonic communication and 500 for telegraph messages. This new cable is the first step in a system which will connect many important centers in the more densely populated parts of the United States.

A High-Voltage Distributing System

BY GLEN H. SMITH[1]
Associate, A. I. E. E.

THE Seattle Municipal Light and Power Plant is operating a 26,000-volt distributing system in an attempt to approach the ideal of constant potential distribution in a rather novel way. The idea which is being developed is to carry the high-voltage lines as close as possible to the consumer's premises, making the primary feeders correspondingly short. By placing the heavier industrial loads on separate power lines and providing a special station with regulators to care for the congested business district, a system is secured that will serve the entire city from three main distributing points with very close regulation and without the use of feeder regulators. The higher voltage lines are naturally more efficient, as our records of distribution losses seem to indicate. The fundamental requirements of safety and reliability are at least as well satisfied by the new system as by the more orthodox one it displaces, and the high-voltage system is certainly more economical and resourceful.

The city of Seattle covers an area of 104.5 sq. mi. of which 36 sq. mi. are water. The city is 14 mi. in length and 6½ mi. wide, and is so shaped that it naturally divides into three parts for electric service; a north, center and south district. The city has 193 mi. of shore line, a large part of which may at any time be the site for some industry needing electric power in large quantities.

The system as planned at present is designed to distribute 480,000 kw., which will take care of the needs of Seattle for a considerable time in the future. There are connected, at present, 85,000 customers with practically every class of lighting and power load, including 6000 residences with electric ranges and a rapidly increasing number with electric heat.

The Seattle Municipal Plant receives its energy from the Skagit River development, north of the city, from Cedar River Station and the City of Tacoma, on the south, and from the Lake Union steam plant in the center of the city. Starting with the steam plant as the central distributing station, the north and south receiving stations are so located that they may be used to advantage for distributing purposes. Each of these three stations is the source of from six to eight 26,000-volt lines, and plans for the future provide as many as thirty lines from each station. All transformers feeding into the 26,000-volt lines are connected in star on that voltage; at the north station, where the transmission voltage is 154,000, a delta-tertiary winding is used to permit the star-to-star transformation. The center point of the star connection is solidly grounded. The voltage at each station bus is kept exactly to schedule by means of synchronous apparatus. Since these points are the only ones in the system which are regulated, except for the station serving the business district as noted later, this voltage schedule is fixed by readings at the consumer's services to give the most satisfactory conditions there.

The 26,000-volt lines are limited in length to about five miles, and are rated at 10,000 kv-a. each, except for direct tie-lines between the three stations, which are rated at 15,000 kv-a. The wire size used for the larger lines is of 300,000-cir. mils copper, with No. 00 B & S gage copper for the smaller ones. The smallest wire permitted on any part of the 26,000-volt lines for safety reasons is No. 2, B & S gage, medium-hard copper. Each line either returns in a loop to the opposite end of the divided bus in its own station, or ties directly to the bus of another station. Line switches for sectionalizing are placed on each side of every tap from the line, and taps to adjacent lines with switches are installed wherever convenient, so that any part of any line may be removed from service for repairs, and there are at least two ways to serve every load.

Scattered along each 26,000-volt line, spaced closely enough so that the 2500-volt primary feeders will be so short and light-loaded that regulators are not needed, distributing stations ranging in size from 50 kw. to 3000 kw. are placed. These substations are made as simple as possible, being mostly little more than pole-type transformers with high voltage fuses and primary and secondary disconnecting switches. As the system grows, it is planned to equip one or more stations in each loop line with relays and oil switches on each side, to disconnect automatically the faulty section of line in case of trouble. Since these substations must be relatively small and numerous, the apparatus in each must be very carefully selected to avoid unnecessary expense. At the present time most of these substations are of the outside type, usually consisting of a two-pole or four-pole rack with transformers and all other apparatus mounted thereon. In many cases it has been possible to locate them on the street, where the topography permits, without objection from adjacent property owners. Others are placed on property purchased for them, in which case relatively cheap inside lots are used. In districts that warrant the expense, the stations are housed in buildings that are designed to harmonize with their surroundings. The stations are unattended, but are regularly inspected and their loading and voltage checked with portable, curve-drawing meters each month or more frequently in the autumn or when there is danger of overload.

1. Engr. Outside Construction, City of Seattle, Seattle, Wash.

Presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

Each substation serves an area of from two to eight sq. mi. according to load density. Three-wire, three-phase, 2500-volt ungrounded delta primaries are used, and the load limited to 200 amperes on No. 4-0 B & S copper. Each 2500-volt feeder is assigned to a definite district, and provision is made for tying to a feeder from another substation at the district boundary, so that any substation may be removed from service in off-peak hours for repairs or extension. Single-phase distributing transformers tapped on the 2500-volt side deliver energy to the customary 120/240-volt, three-wire, single-phase bus for lighting which serves more than 80 per cent of the city's area. Each district is served with single-phase lighting, with the three-phases alternating, but the third-phase wire is always present where polyphase service is needed.

Power loads are usually fed by individual transformers, although there are some districts which warrant and receive separate busses for power. Voltage drop in the 120/240-volt lines and services cannot be compensated for by raising the system voltage to the extent that primary and transformer drop can, so that it is essential that services and busses be of ample size. Three No. 4, B & S copper wires are used on the average residence service where a range is connected; 120/240-volt busses as large as No. 2-0, B & S copper are used in many districts. Transformers are banked together on the low-voltage side, in banks of from four to twelve, and the 2500-volt lines are tied in a network wherever convenient, both to keep down voltage drop and to make the best use of the apparatus.

In the business district of the city, which requires underground service, a single, centrally located station will be used. This station will be fed by four or more 26,000-volt lines by underground cable, and the energy will be distributed by 2500/4300-volt, four-wire, grounded primary feeders, with regulators operating in each phase. There are a number of reasons for making this station an exception to the general system of high-voltage distribution such as the relative expense of station sites, and the advantages of conforming to the existing underground system.

The outstanding advantage that is realized in the high-voltage system as compared with the one it displaces is the increased capacity. A 26,000-volt circuit, carrying 10,000 kv-a. has as much load as should be dependent on one line. Most of the circuits will actually carry much less than that amount, although increasing load densities will eventually require the greatly increased capacities. Voltage regulation is noticeably better from the new system than it was with regulated 2500-volt primaries, largely because of the difficulty of limiting the older primaries to their proper length and loading. The new system is much more flexible and easier to extend to serve new loads of every character. It is also much cheaper to build because of the elimination of heavy feeder wire and much expensive station apparatus.

The efficiency of a distributing system depends as much on the manner in which it is loaded as in its design. Distribution losses for the Seattle municipal system were 18.5 per cent for the year 1924, as compared with 20.6 per cent in 1915. These losses are not excessive for city distribution, and since the lines have been loaded heavier each year, the figures seem to show an increased efficiency for the new system.

The necessity of limiting voltage drop to a low figure insures a fair efficiency of primaries and secondaries, which are brought nearer the theoretical economic size than is the usual practise.

Safety to employes and the public is taken care of in the high-voltage system by making all construction conform to the National Safety Code requirements for heavy loading, and by arranging the lines so that no work need be done on live circuits. It is generally conceded that circuits of comparatively low voltage, such as 2500-volt lines and series street circuits, carry the greatest danger. The Seattle system permits of the use of the lower voltage, delta, 2500-volt primaries, and by eliminating large primary distributing stations materially reduces congestion on pole lines. Many of the features of the system were chosen for reasons of safety, which has been given first consideration everywhere in the design.

Some study was made of probable interference with communication circuits, always to be considered when grounded lines are used. Since no neutral wire is strung, and only three points in the city are grounded, little trouble is anticipated; especially since the primaries are delta-connected.

The trend of development in distribution is toward larger loads and higher voltages. There is increasing pressure to remove overhead wires from the streets and place all circuits underground. A potential of 26,000 volts is conservative for cable, and a circuit of that voltage will carry quite a large block of power, even for modern conditions. The development of machine switching for telephones, and especially the possibilities opened up by the development of radio, point to some form of remote supervision of power circuits and the increase of automatic stations. The 26,000-volt system lends itself ideally to such control, with its distributing points located at each load center.

THE ROOSEVELT BECOMES A FLOATING POWER HOUSE

The famous ship upon which Admiral Peary went to the Artic in search of the North Pole has had a varied career. She was built in a Maine shipyard. Later she was brought to Puget Sound and was converted into a sea-going tug. After this the *Roosevelt* saw considerable service with the fishing fleets of the Pacific and now she is taking the place of the electric generating station, which was recently destroyed by lightning, on Vashon Island in Puget Sound, acting as a floating power house until a new one upon land can be built.

Mississippi River Crossing of Crystal City Transmission Line

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Synopsis.—The description and illustrations which follow refer to overhead wire crossing of the Mississippi River near Crystal City, Mo., of a double circuit, 132,000-volt, three-phase, 60-cycle transmission line now in the process of construction. The terminal points of this line at the present time are the Cahokia steam power station of the Union Electric Light & Power Company and the glass manufacturing plant of the Pittsburgh Plate Glass Company at Crystal City, Mo. The general location of this line is shown in the accompanying map, Fig. 1. Its length is 30.8 miles, (49.6 km.), of which 28.4 miles (45.7 km.) are in Illinois and the remainder in Missouri and in the river crossing. The purpose of this article is primarily to describe the problems involved in the river crossing.

At the point of crossing, the Mississippi River is approximately 4000 ft. (1220 m.) wide, bank to bank. On the Missouri side there is a high limestone bluff the top of which is at elevation 745 with reference to Memphis, Tenn. datum. The average ground level on the Illinois bank is at elevation 395 or 350 ft. (106.8 m.) lower than the Missouri bluff, opposite.

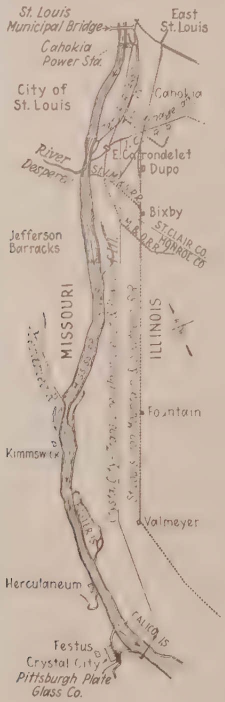


Fig. 1—Map Showing Location of Transmission Line and Mississippi River Crossing

The hydrographic records of the Mississippi River indicate that extreme high water in 1844 was at elevation 410.5 and high water in 1903, at elevation 406. A levee protecting the Illinois low lands parallels the river for a distance of approximately 6500 ft. (1983 m.) from the Missouri bluff. The Illinois shore at, this point between the river's edge and the levee, is known as Calico Island.

It is observed from the foregoing figures that any foundation between the levee and the Missouri bluff would be in an area subject to overflow and in addition would be subject to the characteristic scouring action of the Mississippi River during each such overflow period.

In order to obtain data for the design of foundations for towers two test borings were made to rock on the Illinois bank, the first at a distance of approximately 400 ft. (122 m.) from the river's edge and the second about 50 ft. (15.3 m.) from the edge. Both of these borings showed that the ground was typical river bed deposit consisting of fine silt on the top strata, the lower strata consisting of coarse sand and gravel, the gravel increasing in size to stones several inches in diameter as rock was approached. Since these data checked closely with numerous other borings of the Illinois bed of the river between this location and East St. Louis, Ill., it was not considered necessary to make more than the two borings taken. Government records (House document No. 762, 63rd Congress, 2nd Session) contain reports of test borings taken over a distance of four miles east and west beginning at Steins Street, St. Louis, on the Missouri bluff to the Illinois bluffs. The borings on Calico Island showed deposits very similar to the government borings. Other boring data available were those made at the time of construction of the four bridges spanning the Mississippi at St. Louis and those for the Cahokia power station below East St. Louis, Ill.

The Federal requirements with respect to river clearance at this point called for a mechanical clearance of 64 ft. (19.5 m.) from the lowest point of the sag to high water elevation on the basis of 1903 high water. It was considered advisable to add 10 feet (3.05 m.) for electrical clearance making total clearance 74 feet (22.6 m.)

The preceding description outlines the physical problem; the solution of the problem was made as follows:

It is apparent from the data given that to support a

1. Both of Union Electric Light & Power Co. of Illinois, St. Louis, Mo.

Abridgement of paper presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925. Complete copies to members upon request.

crossing span on towers outside the area of overflow would involve a span distance of 7000 feet (2135 m.) It was determined, therefore, to construct the crossing in two spans supported by three towers, the western tower to be placed on top of the Missouri bluff, the intermediate tower approximately 300 ft. (91.5 m.) from the existing water's edge on the Illinois bank, and the third tower a short distance east of the levee. It was further decided to arrange the Missouri tower and the Illinois levee tower as anchor structures, both designed to support the unbalanced stress of all six conductors under worst conditions of ice and wind loading, and to arrange the intermediate tower so as to support the conductors on insulators in suspension position.

Sketch, Fig. 2, shows all these data in graphical form. From this sketch it will be observed that the horizontal distance between the Missouri tower and the intermediate tower is 4279 ft., (1305 m.) and the horizontal distance between the intermediate tower and the Illinois terminal tower, 2681 ft., (818 m.) The profile

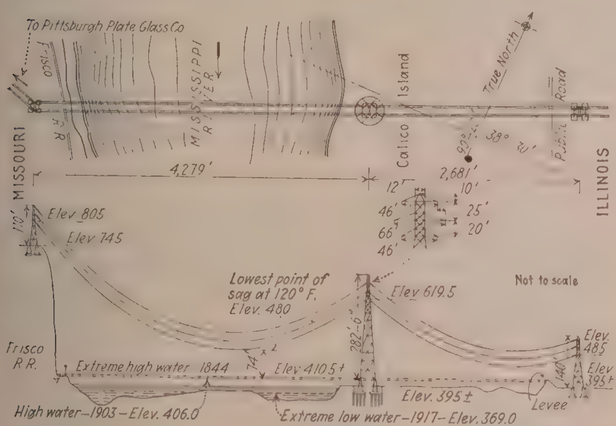


Fig. 2—Plan and Profile of Mississippi River Crossing

shows clearly the different elevations involved. The clearance to river level is shown on the basis of conductor sag at 120 deg. fahr. (48.8 deg. cent.) and under extreme assumption that such sag will occur with the river at an elevation duplicating that of 1903.

The lowest cross-arm of the Missouri tower will be 60 ft. (18.3 m.) above its base. The lowest cross-arm of the intermediate tower will be 227½ ft. (69.5 m.) above its base, and the lowest arm of the Illinois anchor tower will be 90 ft. (27.5 m.) above its base.

The three conductors of each circuit are to be carried across the river in vertical configuration. From the tower details shown in Fig. 2 it will be noted that there will be a vertical separation of 20 ft. (6.1 m.) between the conductors of each circuit at the two anchor towers, but a vertical separation of 25 ft. (7.6 m.) between the top conductor and the middle conductor at the intermediate tower, and a vertical separation of 20 ft. (6.1 m.) from the middle conductor to the lowest conductor at the intermediate tower. It will be further noted that the center conductors are to be offset outwardly from the towers 10 ft. (3.m.) with respect to the top and bottom conductors, both of the latter being at the same distance from all towers. The length of the crossarms are based upon,—

1. The foregoing vertical and horizontal separations of the conductors
2. The length of the assembly of insulating supports, hardware, etc., as will be discussed later, and
3. A minimum clearance to steel structure of 4½ ft. (1.37 m.) with conductor swung at an angle of 45 deg. from the vertical toward the tower

It will be observed that this has resulted in top and bottom crossarm length of 46 ft. (14.03 m.) and middle cross-arm length of 66 ft. (20.2 m.)

It will be found upon a detailed analysis of a problem of this character that the final solution of;

a. The strength of crossing conductors
b. The insulating supports at the towers
c. The towers themsevles
d. The tower foundations

are interdependent one upon the other and that a joint solution of all four phases of the problem must be made more or less simultaneously. The resulting composite solution should be the one which results in allowing ample factors of safety and the lowest overall total cost of the crossing.

The specific economical study of this particular problem has resulted in the selection of a steel-reinforced aluminum conductor to be employed. The design tension for the conductors and for the other three factors of the major problem was taken as 33,000 lb., (15,000 kg.) which will occur under conditions of ½-in. (1.27 cm.) ice loading at 0 deg. fahr. (−17.7 deg. cent.) and 12 lb. per square foot wind pressure. (58.7 kg. per sq. m.)

The specific requirements which each of the four major elements should meet were then chosen as follows:

1. Towers

a. Anchor Towers. The anchor towers are to be capable of withstanding the unbalanced pull of six conductors with 33,000-lb. (15,000 kg.) tension in each. The design of the tower steel members specifies unit stress requirements to be in accordance with the National Electrical Safety Code for the above loading with the tower steel computed on a basis of 50 per cent overload on the above specific loading. The tower foundation specification requires these to be designed for 75 per cent overload with respect to the above specific tower loading. In addition to the ice and wind loading on the conductors, the tower is required to meet an ice weight and wind loading produced by the weight of ½ inch ice covering on its members and with a wind pressure equivalent to twice the area of one side on the basis of 25 lb. per square foot pressure (122.2 kg. per m²).

b. Intermediate Tower. The specification for the intermediate tower gives the maximum loading as three

broken conductors with a tension of 33,000 lb. per conductor. The tower steel is to be designed on the basis of 50 per cent overload on this specific loading and with unit stresses on the design basis in compliance with the stresses of the National Electrical Safety Code. In addition to the ice and wind loading on the conductors the tower steel design includes the additional load produced by the weight of ½-in. ice covering on its members and with a wind pressure equivalent to twice the area of one side on the basis of 25 lb. per square foot pressure (122.2 kg. per sq. m.)

2. Foundations

General. Since the three towers are of different heights and impose different loadings on their foundations, and since these in turn have different soil conditions, separate foundation computations were required for each tower. For the purpose of foundation data for the anchor towers, the shoreward conductors were assumed broken. It was considered that the unbalanced pull of the conductors on these towers would always be in a direction toward the river and that in consequence the piers on the river side would always be under compression at time of maximum load and those on the land side under uplift conditions. Advantage was taken of this in reducing the size of the two compression piers as compared to the uplift piers.

For the intermediate tower it was concluded that all four piers should be of similar design.

For the two anchor towers, which are at locations not subject to overflow, the full weight of the backfill earth and of the concrete piers is taken into account in resisting the uplift of the base.

In the case of the intermediate tower the weight of the earth backfill was not considered in calculating the uplift quantities and the concrete was figured for its uplift value when submerged in water.

The total reaction and uplift figures for all foundation calculations are indicated in the accompanying Table I.

These conditions have resulted in foundations of the following specific dimensions:

1. Missouri Tower

a. Shoreward Piers. Each of these two piers consists of a reinforced concrete base pad 20 ft. (6.1 m.) square and 2 ft. (0.6 m.) thick from which rises a pier 12 ft. (3.66 m.) square at the base, tapering to 4 ft. (1.22 m.) square at the top, which is 9 ft. (2.74 m.) above the top of the base pad. The entire block is liberally reinforced with formed steel rods. The foundation bolts 2¼ in. (5.72 cm.) in diameter and six in number for each pier, extend 10 ft. (3 m.) into the concrete. Pairs of bolts are tied together with angle plates and reinforcing rods, in turn, are looped over the top of these angles.

b. Riverward Piers. These piers are the same as the shoreward piers with the exception that the base pad is 14 ft. (4.17 m.) square instead of 20 ft. (6.1 m.) square.

TABLE I

Reactions	*Wire Pull	Wind	Dead Load	Total
110 Ft. (33.5 m.) Tower—Illinois Bank				
Piers toward river	313,100 lb. (142200 kg.)	15,600 lb. (7090 kg.)	25,500 lb. (11600 kg.)	354,200 lb. (161200 kg.)
Uplifts Piers toward bank	285,700 lb. (129700 kg.)	15,600 lb. (7090 kg.)	25,500 lb. (11600 kg.)	275,800 lb. (125200 kg.)
Tower weight				132,000 lb. (60000 kg.)
140 Ft. (42.8 m.) Tower-Missouri Bank				
Reactions Piers toward river	326,200 lb. (148400 kg.)	20,100 lb. (9140 kg.)	31,500 lb. (14320 kg.)	377,800 lb. (171500 kg.)
Uplifts Piers toward Bank	298,800 lb. (136200 kg.)	20,100 lb. (9140 kg.)	31,500 lb. (14320 kg.)	287,400 lb. (130700 kg.)
Tower weight				160,000 lbs. (72727 kg.)
285 Ft. (87. m.) Tower-Suspension Type				
Reactions	258,450 lb. (117500 kg.)	47,300 lb. (21480 kg.)	66,500 lb. (30200 kg.)	372,250 lb. (169400 kg.)
Uplifts	225,050 lb. (102080 kg.)	47,300 lb. (21480 kg.)	66,500 lb. (30200 kg.)	205,850 lb. (93700 lb.)
Tower weight				288,000 lb. (131000 kg.)

*Weight of wire has been added to reactions and subtracted from uplifts. 16700 lb. (7600 kg.) for 285 ft. (86.8 m.) tower; 13,700 lb. (6230 kg.) 110 (33.5 m.) and 140 ft. (42.8 m.) towers.

All of these foundations are located in hard clay soil on top of a limestone rock bluff. The centers of the piers form a square 32 ft. (9.77 m.) on sides.

2. Illinois Anchor Tower

a. Shoreward Piers. These piers are the same as the shoreward piers of the Missouri anchor tower.

b. Riverward Piers. The riverward piers are the same as the shoreward piers except that the base mat is 17 ft. (5.18 m.) square instead of 20 ft. (6.1 m.) square.

All of these foundations are in silt and sand river bottom land.

The foundation bolts are the same in size and number and arranged in similar manner to those for the Missouri tower. The centers of the piers form a square 42 ft. (12.8 m.) on a side.

3. Intermediate Tower

From the boring data mentioned in the preceding part of this article, it was evident that the foundations for the intermediate tower would be required to rest upon piles. From a study of the boring data and the tower uplift and reaction figures given in the preceding tabulation, the arrangement shown in Figs. 3 and 4 was selected. From Fig. 3 it will be noted that each of the four piers is to be supported upon a cluster of sixteen 35 ft. (10.8 m.) reinforced concrete piles driven so that their points will be at elevation approximately 339, *i. e.*, to a depth 47 ft. (14.35 m.) below the present ground level. Each of these piles is to be 15 inches (38.1 cm.) square and the steel reinforcing is so arranged as to connect the pile head with the base of the foundation pier. The base of the foundation pier is approximately square in shape, 17 ft. (5.18 m.) on a side and 6

ft. (1.83 m.) thick. From the top of this base the pier proper tapers from a dimension 11 ft. (3.4 m.) square at its base to 5 ft. (1.52 m.) square at the top. The top is at elevation 407, or 1 ft. (0.3 m.) higher than 1903 high water elevation. Six foundation bolts, 1⅞ inch (4.76 cm.) in diameter, are buried in this concrete pier to a depth of 10 ft. (3.05 m.) The bottoms of pairs of bolts

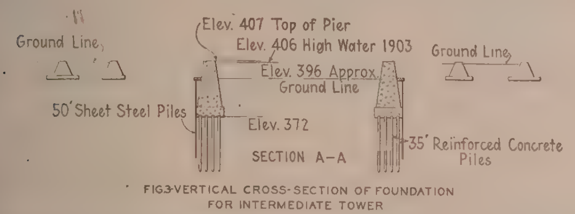


Fig. 3—Vertical Cross-Section of Foundation for Intermediate Tower

are tied together by substantial angle plates and hairpin shaped reinforcing rods in turn extend from the bottom of the pier over the tops of these angle plates. Thus, it will be seen that through the arrangement of the reinforcing employed, tension stresses of the pier are transmitted from the top of the pier to the bottom of the concrete piles. From Fig. 4 it will be observed that the centers of the four piers form a square 80 ft. (24.4 m.) on sides.

To protect these foundations against scour action of the river, it was decided to employ an envelope of steel sheet piling surrounding all four foundations. From Fig. 4 it will be observed that this piling is to be driven in the form of a circle 130 ft. (39.8 m.) in diameter, the outer edges of which are in contact with the outer edges of the foundation bases. The sheet steel piling consists of 50-ft. (15.25 m.) lengths made up with 2 per cent copper. From Fig. 3 it will be noted that a circular, reinforced-concrete girder (1½ ft. by 6 ft. (.46 m. by 1.83 m.) cross section is to extend around the entire top perimeter of the steel piling and to be bonded to the outer edges of each of the four foundations. Thus, this girder will act as a stiffener to the piling and at the same time will reinforce the four base cords of the steel tower. The concrete will also protect the steel piling against rust at the ground line.

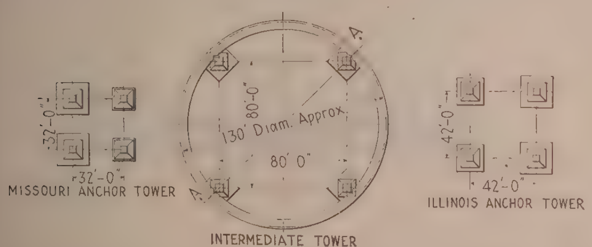


Fig. 4—Plan View All Foundations and Scour Apron for Intermediate Tower

Fig. 5 illustrates the process of driving this steel sheet piling envelope. The steel sheet piling was driven by means of a steam hammer suspended from the end of derrick boom and supplemented by 300-lb. per sq. in. pressure water jet. (21.5 kg. per cm².)

Fig. 6 shows (a) the process of driving steel sheet piling for the excavation for the cofferdam for an individual foundation pier, and (b) the method of driving concrete piling in one of these excavations. Note that the steel sheet piling envelope shown in the foreground has been driven to ground level.

Fig. 5—Construction Progress Driving Steel Sheet Piling Apron Intermediate Tower

Fig. 7 shows the interior view of steel sheet piling cofferdam for one of the foundation piers for the intermediate tower. One of the concrete piles is shown in position ready to be driven.

Fig. 6—(a) Construction Progress Driving Sheet Steel Piling for Foundation Pier Excavation
(b) Driving Concrete Piles in one of These Excavations

The concrete piles were driven by the combined efforts of standard pile driver hammer supplemented by 300-lb. per sq. in. (21.5 kg. per cm.²) pressure water jet. In driving the piles the ground was first partially excavated, the sides of the excavation held in place by steel sheet piles and the concrete piles then driven as above to proper cut-off.

A few special features of the river crossing towers may be of interest. Access to the top of each tower will be by means of a ladder the steps of which will be steel bars 4 by ⅜ by 11 in. (10.2 by .95 by 27.9 cm.) bolted to two angles carried up the center of one face of the tower.

From the top of the first panel of the tower, or 15 ft. (4.57 m.) above the base, these steps will be enclosed in a safety basket extending to the top of the tower and with rest platforms at convenient intervals. The bottom of this safety ladder will be provided with gate and padlock. The width of each cross-arm will be 12 ft. (3.66 m.). To provide working space for men, each of these cross-arms will be constructed as a platform employing subway type grating for flooring and with hand-railings 3 ft. (0.9 m.) high on each side. The space within the basket at the top of each tower will be used for storage boxes to store spare insulators and hardware, construction tools and tackle for the tower. All of these towers will be hot galvanized and will be bolted.

4. Conductors

The conductors for the river crossing consist of 318,000-cir. mil steel reinforced aluminum cables for 250 amperes maximum current requirements, and each cable was purchased as one 7500-ft. (2290-meter) continuous length, one spare conductor being supplied.

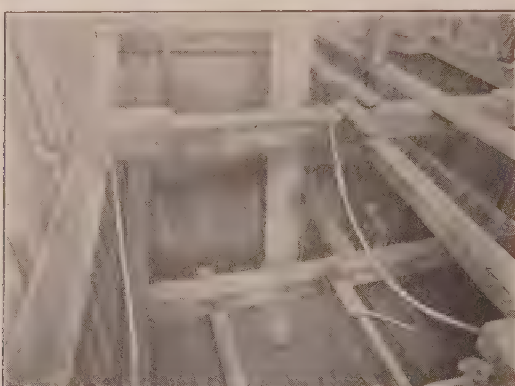


Fig. 7—Interior View of Steel Sheet Piling Cofferdam for Foundation Pier for Intermediate Tower

The steel core consists of 43 strands of various size galvanized steel wires so woven that all wires are woven in the same direction without the crossing of one strand over another. Long experience elsewhere with a number of long crossing spans has indicated the desirability of this arrangement for the purpose of reducing the possibility of breakage of strands due to gradual wearing of one strand into another at points of crossing. Surrounding the steel core are 24 strands of aluminum wires approximately 0.1151 inches (2.92 mm.) in diameter. The aluminum strands are woven on the steel core in a direction the reverse of that of the steel strands. The steel core is to be made up of strands each of which is to be a continuous length without weld, braze, or splice of any character. The above results in a cable the outside diameter of which is approximately 1.036 in. (2.55 cm.) The overall diameter of the steel core will be 0.807 in. (2.05 cm.) with a breaking strength of 64,000 lb. (29,100 kg.) The ultimate strength of the completed cable is 67,600 lb. (30,700 kg.) and its elastic limit 53,500 lb. (24,300 kg.) The weight of completed bare cable will be 1.684 lb. (0.765 kg.) per foot.

The disposition of towers, cross-arms, etc., as above described will result in the following elevations at various locations of lowest conductor:

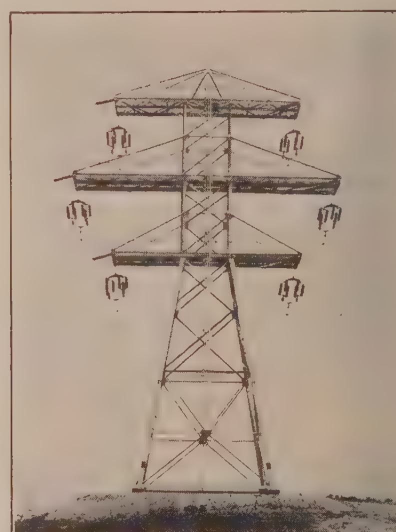
a. Cross-arm attachment on the Missouri end at elevation 805

b. Lowest point of sag at elevation 480 at temperature 120 deg. fahr. (48.9 deg. cent.)

c. Conductors at the intermediate tower at elevation 620

d. Cross-arm attachment at the Illinois terminal tower at elevation 485

Under these conditions the vertical sag at 120 deg. fahr. (48.9 deg. cent.) without wind will be 325 ft. (99 m.) below the Missouri tower support.



Missouri Strain Tower, Showing Method of Attaching Conductors

The sag and tension figures for other conditions of ice and wind loading, temperature, etc., are given in Table II below. As an appendix to this article are given the

TABLE II
STRINGING SAGS AND TENSIONS

Temperature	Loading	Sag below Upper Support	Sag below Lower Support	Tension
0° F. (−17.8° C.)	½ in. ice 12 lb. wind (1.27 cm. 58.5 kg/sq. m.)	318.3′ (Res.) (97. m.)	171.5′ (Res.) (52.3 m.)	33,500 lb. (15000 kg.)
32° F. (0°(C.)	½in. ice no wind (1.27 cm.)	328.3 ft. (100. m.)	142.8 ft. (45.1 m.)	27,370 lb. (12400 kg.)
−20° F. (−28.9°C.)	no ice, no wind	312.8′ (95.1 m.)	127.3′ (38.8 m.)	18,770 lb. (8500 kg.)
32° F. (0° C.)	no ice, no wind	317.5′ (96.7 m.)	132.′ 40.3 m.)	18,380 lb. (8320 kg.)
60° F. (15.6° C.)	no ice, no wind	320.′ (97.5 m.)	134.5′ 41.0 m.)	18,160 lb. (8250 kg.)
120° F. (48.9° C.)	no ice, no wind	325.′ (99.1 m.)	139.5′ (42.6 m.)	17,710 lb. (8050 kg.)

complete calculations of sags and tensions from which the values in the tabulation were derived.

5. Insulated Supports

The requirements to be met by the insulated supports for the conductors have been suggested above in the discussion with respect to the conductors. For the purpose of selecting the insulator linkages the maximum tension of the conductor was taken as 35,000 lb. (15,900 kg.) and a mechanical factor of safety of two was selected on the total linkage to be employed. The insulators

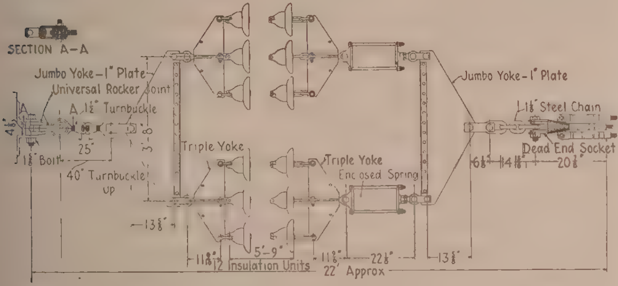


Fig. 8—Assembly of Conductor Insulating Supports for Anchor Tower

are each to be proof-tested at 12,000 lb. (5450 kg.) and to have a maximum ultimate strength of 18,000 lb. (8200 kg.) each.

a. Supports at Anchor Towers. To meet the above conditions six strings of insulator disks of this description are required per conductor at each anchor tower, these to be arranged in two groups of three strings each. The three strings of 12 disks are to be assembled with triple yokes top and bottom and two sets of triple yokes to be combined by one jumbo yoke at top and bottom. Details of this assembly are shown in Fig. 8 from which it will be noted that the overall distance from the cross-arm to the conductors is approximately 22 ft. (6.7 m.)

The following features of interest are pointed out with respect to this arrangement. The attachment at the cross-arm consists in effect of a universal joint made of two steel forgings. Motion in a vertical plane is obtained about the 1⅝-inch (4.13 cm.) diameter steel pin mounted in the cross-arm clips and motion in a horizontal plane is obtained by rocker shaped surfaces on the two forgings. A turn-buckle is next provided which provides two feet of take-up. The jumbo yoke is long enough to permit proper equilization of tensions on the six strings of insulators. The holes shown in the triple yokes are for the purpose of attaching outriggers for pulling up the strings of insulators to permit of replacements. Next to the outer triple yoke is a double car spring which will be calibrated so as to show the tension on the insulator strings at any time. It is believed that these springs will also act as shock absorbers in the case of sudden movement of the conductors due to ice falling from them, etc. Next to the outer jumbo yoke are shackles and four links of heavy dredge chain. The entire structure has been designed for a maximum of flexibility and equalization of stresses over the individual insulator strings. With the exception of the steel casting covers of the car springs all metal parts even the insulator caps are made of steel forgings or plates.

The specification calls for a test of the completed assembly of three strings of insulators of 35,000 lb. (15,900 kg.) and of the completed assembly of six strings of insulators at 70,000 lb. (31,800 kg.)

The form of clamp employed at the end of the linkage for attaching to the conductors and the method of handling the conductors are also of special interest. This clamp consists of an aluminum body clamp which is compressed about the exterior of the complete steel reinforced aluminum cable by means of three compressions. The aluminum conductors are then cut off and the steel core continued into a steel Roebling bridge socket into which they are sweated with zinc. The aluminum body clamp and the steel core socket clamp are both carried by a common steel bolt 1⅝ inch (4.13 cm.) in diameter.

The details of this dead-end socket clamp are shown in Fig. 9 The aluminum body clamp contains three projections, the purposes of which are as follows. To one projection will be bolted two small aluminum body clamps attached by compression joints to two lengths of 300,000-cir. mil A. C. S. R. conductors of the type employed in the land transmission line. These two cables arranged in parallel horizontally will then be carried as the loop connection under the cross-arm from the river span dead end to the land span dead end. They will be clamped at five-foot intervals with three-bolt, parallel-groove aluminum clamps. The purpose of this latter arrangement is to stiffen the loop and hold

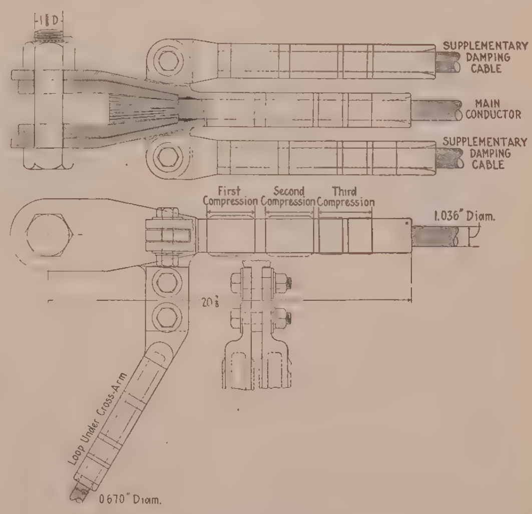


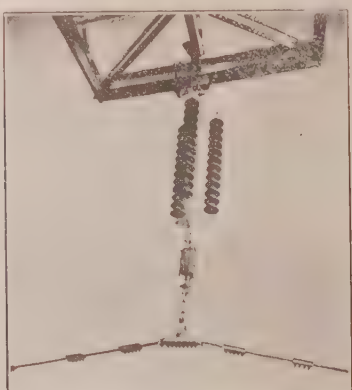
Fig. 9—Detail of Conductor Cable Socket Clamp for Anchor Towers

to a minimum its swinging with the wind toward the tower. This precaution is of importance on account of the extreme length of these loops which will be about 45 feet (13.75 m.).

As shown in Figs. 8 and 9, there will be bolted to each of the other two projections on the main aluminum body clamp another aluminum body clamp which will

be attached by compression joints to a length of supplementary 318,000-cir. mil A. C. S. R. cable which will parallel the main cable for a distance of 20 ft. at the dead end in one case and 15 ft. in the other, and be clamped to it by means of parallel-groove aluminum clamps.

As is well known, long transmission line spans involving high wire tensions are peculiarly susceptible to vibration, the laws of which are not so well known. The vibration, however, has a definite nodal point at the junction with the cable clamp resulting in a tendency for the strands of the cable to break at the point of attachment. The result of study by others of vibration in existing spans indicates that the probability of damage will be materially reduced by spreading the vibration over a number of clamps arranged in parallel, and increasing in mass as above described.



Conductors in Suspension Position to Intermediate Tower

b. Supports at the Intermediate Tower. As indicated in the description of the intermediate tower itself, the conductors are to be supported by insulators arranged in suspension. This arrangement is in conformity with that followed throughout the rest of the line where every effort has been made to reduce to an absolute

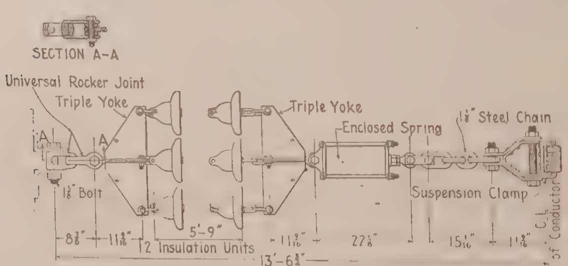


Fig. 10—Assembly of Conductor Insulating Supports for Intermediate Tower

minimum the number of dead-end insulator assemblies. In the river crossing the dead-ending of the conductors on the two terminal towers was a physical necessity. The dead-ending of these conductors was not necessary on the intermediate tower, and accordingly is not employed. In case of breakage of either span the linkage at the intermediate tower is strong enough under its normal strength characteristics to hold the remaining span without slippage. The reasoning behind this arrangement was as follows:

All records indicate that this crossing is in a region of heavy sleet loading. It was considered possible that the span between the intermediate tower and the Missouri anchor tower might be coated with ice while the east span from the intermediate tower to the Illinois anchor tower might not be so coated. This is not an unusual condition in transmission line work and follows usually from the sleet having melted and fallen from one conductor span before doing so in the adjacent span. Under such condition it was considered that if the conductors were carried on rollers or sheave wheels on the intermediate tower, the unbalanced loading of ice on the river span would cause an excessive sag in this span. To prevent just such occurrence or the reverse occurrence of the pulling down of the long land span between the intermediate tower and the Illinois terminal tower it was considered that the conductor should be definitely clamped to the insulator string at the intermediate tower.

Intermediate Tower in Foreground; Missouri Tower in Background

Figs. 10 and 11 show the insulator and conductor clamp assembly selected. The order of assembly of the insulator strings, hardware, conductor clamp, etc., are similar to those employed on the dead-end towers, except that a single group of three strings of insulators in parallel is employed. The insulators and hardware exclusive of conductor clamp are the same as those used on the anchor towers and need no further description. The following specific features of the conductor clamp are of interest:

The conductor clamp consists of two aluminum castings bolted together about the conductor and supported from the insulator assembly in a substantial steel saddle. The cable grooves in the aluminum clamp approximate the position the wire will take due to its normal sag. Paralleling the main conductor will be two supplemen-

tary lengths of cable of the same character as the main cable and bolted to it by means of parallel-groove clamps for distances of approximately 20 ft. and 15 ft. respectively on each side of the main supporting clamp. The use of the supplementary cables and clamps constitutes the treatment of the vibration problem in a manner similar to that used on the dead ends on the anchor towers.

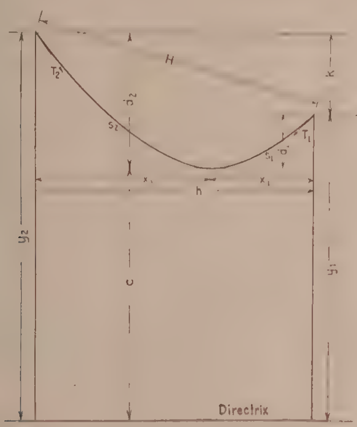


FIG. 18—GRAPH FOR APPENDIX

SYMBOLS

h = horizontal distance between supports.
x_1 = horizontal distance from lower support to the vertex of the catenary
x_2 = horizontal distance from the upper support to the vertex of the catenary
H = air line distance between the upper and lower supports
y_1 = the height of the lower support above the "directrix" or reference line of the catenary
y_2 = height of the upper support above the "directrix" or reference line of the catenary
c = height of the vertex of the catenary above the "directrix"
s_1 = length of the suspended wire from the lower support to the vertex of the catenary
s_2 = length of the suspended wire from the upper support to the vertex of the catenary
l = total length of the suspended wire
T_1 = the tension in the wire at the lower support
T_2 = tension in the wire at the upper support
d_1 = sag below the lower support
d_2 = sag below the upper support
k = the difference in elevation between the lower and upper supports
p = pressure per unit length of wire of wind on the ice covered wire
w_i = weight per unit length of wire of the ice on the bare wire
w_c = weight per unit length of bare wire
E = modulus of elasticity of the material carrying the stress
A = cross-section area of the material carrying the stress
α = coefficient of linear expansion Fahrenheit of the material carrying the stress

For the reasons outlined above it is also considered necessary that this clamp shall prevent excessive slippage of the conductor during any unbalanced loading due either to ice or a break in the adjacent span. This is of particular importance from the standpoint of river navigation as well as of operation of the circuit. The specification requires that this clamp shall hold the cable against slippage at 35,000 lb. (15,900 kg.) tension in the event of breakage of one of the spans.

The foregoing description applies to the design of the river crossing only.

Appendix

The calculation of the performance of flexible cables and wires in equilibrium for supports at equal elevations and for short spans may be approximated to the extent of employing the parabolic form of equations or any one of a number of sets of prepared tables or charts. The ordinary tranmission line range of span seldom exceeds 1200 ft. and for such spans the values calculated by such methods serve all practical purposes.

However, when the specific problem arises of a long span and the supports are so arranged as to be at unequal elevations, and when it is important that certain clearances over navigable waters must be maintained and a certain stress is not to be exceeded, the economy of design and assurance of performance require some more rigorous calculation.

The calculation of long spans with supports at unequal elevations arises infrequently, and but little has been published to indicate the method of solving the performance of such spans.

Calculation of River Crossing

SPAN 4279 FT. MAXIMUM TENSION 33,000 LB. AT 0 DEG. FAHR. ½ IN. ICE AND 12 LB. PER SQ. FT. WIND

Cable Data

Size.....................318,000 cir. mil, A. C. S. R.
Stranding...............24 x 1151 Aluminum
43 strands various size steel

Steel core stranding

Number of Strands	Diameter
1	0.127 in.
6	0.120 in.
6	0.052 in.
12	0.115 in.
18	0.112 in.

Overall diam.	0.804 to 0.810 in.
Total sectional area (*A*)	0.3952 sq. in.
Wt. per ft.	1.386 lb.
Breaking Strength	64,000 lb.
Diam. of complete cable-overall	1.036 in.
Elastic limit of complete cable	53,500 lb.
Breaking strength of complete cable..................	67,600 in.
Modulus of elasticity (*E*) for steel	3×10^7 lb./in.^{2}
For steel core alone *E A*...	11,856,000 lb.

	Vertical		Horizontal
	Dead	Dead + ½ in. Ice	12 lb. Wind
Weight, lb. per ft...	1.684	2.623	2.036

	Resultant
	Dead + ½ in. Ice + 12 lb. Wind
Weight, lb. per ft....	3.322

The calculations which are to follow will be based upon the assumption that all the stress will be carried on the steel core only.

At 0 deg. fahr., ½ in. ice + 12 lb. wind

$k = 185.5, \quad h = 4279.$

$T_2 = 33{,}000$

$\delta\ k = k(\cos\ \theta - 1) = -38.64$

$w = 3.322$

$h_0 = 4280.50$

$k_0 = 146.86$

$y_2 = 9933.77$

$y_1 = 9786.91$

$$h = -\frac{2\,k\,\delta\,k + (\delta\,k)^2}{2\,h} = 1.50$$

Determine c from

$$c^2 \,.\, \cosh \frac{h_0}{c} - \sqrt{(y_1^2 - c^2)\,(y_2^2 - c^2)} - y_1 \,.\, y_2 = 0$$

Let c =	9620.00	9615.00	9616.00	9615.44
(1) $c^2 \,.\, \cosh \frac{h_0}{o}$	101,858,646	101,762,630	101,781,830	101,771,077
(2) $\sqrt{(y_1^2 - c^2)\,(y_2^2 - c^2)}$	4,458,003	4,559,017	4,538,836	4,550,139
(3) $y_1 \,.\, y_2$	97,220,913	97,220,913	97,220,913	97,220,913
(4) (2) + (3)	101,678,916	101,779,930	101,759,749	101,771,052
(5) (1) − (4)	179,730	−17,300	22,081	25

The value of c = 9615.44

for c = 9615.44

s_1 = 1923.99

s_2 = 2494.61

l = 4318.60

At 32 deg. fahr. ½ in. Ice and 12 lb. Wind

$$\delta l = l \,.\, \alpha \,.\, \delta t$$

$$\alpha = 0.00000662$$

$$\delta t = 32$$

$$\delta l = 0.91485222$$

$$\delta c = \frac{\dfrac{l}{\sqrt{l^2 - k_0^2}}}{2\sqrt{\dfrac{y_1\,y_2 + s_1\,\,s_2 - c^2}{2\,c^2}} - \dfrac{h_0}{c}\sqrt{\dfrac{y_1\,\,y_2 + s_1\,\,s_2 + c^2}{2\,c^2}}}\,\delta l$$

$$\frac{l}{\sqrt{l^2 - k_0^2}} = \frac{4318.60}{4316.102} = 1.0005787$$

$$2\sqrt{\frac{y_1\,y_2 + s_1\,s_2 - c^2}{2\,c^2}} = 0.44887198$$

$$\frac{h_0}{c}\sqrt{\frac{y_1\,y_2 + s_1\,s_2 + c^2}{2\,c^2}} = (0.44518711)\,(1.0248763)$$

$$= 0.45626173$$

$$\delta c = \frac{(1.0005787)\,\delta l}{0.44887198 - 0.45626173} = -\,123.87180$$

$$\delta y_2 = \frac{\delta l + \left(\dfrac{c}{s_1} + \dfrac{c}{s_2}\right)\delta c}{\left(\dfrac{y_1}{s_1} + \dfrac{y_2}{s_2}\right)}$$

$$= \frac{0.91485222 + (5.2716517 + 3.8544863)(-123.87180)}{(5.3656599 + 3.9820934)}$$

$$\delta y_2 = -\,120.81580$$

$$\delta T_2 = w\,\delta y_2 = -\,401.35$$

T_2' = 32598.65

y_2' = 9812.96

y_1' = 9666.10

$k' = k_0$ = 146.86

$h' = h_0$ = 4280.50

c' = 9491.57

l' = 4319.51

s_1' = 1828.87

s_2' = 2490.64

w' = 3.322

At 32 deg. fahr. ½ in. ice, no wind

$\delta w'$ = −.699

$\delta k'$ = 38.64

$\delta h'$ = −1.50

$$\delta l' = \frac{k'\,\delta\,k'}{l'} + \frac{\sqrt{(l')^2 - (k')^2}}{l'}\left[\left(2\sqrt{\frac{y_1'\,\,y_2' + s_1'\,\,s_2' - (c')^2}{2\,(c')^2}}\right.\right.$$

$$\left. - \frac{h'}{c'}\sqrt{\frac{y_1'\,\,y_2' + s_1'\,\,s_2' + (c')^2}{2\,(c')^2}}\right)\delta c$$

$$\left. + \left(\sqrt{\frac{y_1'\,\,y_2' + s_1'\,\,s_2' + (c')^2}{2\,(c')^2}}\right)\delta h'\right]$$

$$= 1.3137301 + (0.99942192)$$

$$[(0.45482378 - 0.46249362)\,\delta c' + 1.5382983]$$

$$\delta l' = 0.2245682 - 0.007665406\,\delta c'$$

$$\delta y_2' = \frac{\delta l + \dfrac{y_1'}{s_1'}\,\delta k' + \left(\dfrac{c'}{s_1'} + \dfrac{c'}{s_2'}\right)\delta c'}{\dfrac{y_1'}{s_1'} + \dfrac{y_2'}{s_2'}}$$

$$\delta y_2' = \frac{-.2245682 - .007665406\,\delta c' + 204.22343 + 9.000750\,\delta c'}{9.2252205}$$

$$\delta y_2' = 22.113169 + 0.97483691\,\delta c'$$

$$\delta y_1' = \delta y_2' - \delta k'$$

$$\delta y_1' = -\,16.526831 + 0.97483691\quad c'$$

$$\delta l' = \frac{l'}{E\,A}\,.\,\delta T_2'$$

$$\delta T_2' = (w' + \delta w')\,.\,\delta y_2' + y_2'\,.\,\delta w'$$

$$\delta l' = \frac{l'}{E\,A}\,[(w' + \delta w')\,\delta y_2' + y_2'\,.\,\delta w)]$$

$$-0.2245682 - 0.007665406\,\delta c' = \frac{4319.51}{11856000}$$

$$[(2.623)(22.113169 + 0.97483691\,\delta c') + (9812.96)(-.699)]$$

$$= 0.00036433114(58.002482 + 2.5569972\,\delta c' - 6859.20)$$

$$-0.2245682 - 0.007665406\,\delta c'$$

$$= -2.4779094 + 0.0009315837\,\delta c' - 0.0085969897\,\delta c'$$

$$= -2.2533412$$

$\delta c'$ = 262.10816

$\delta y_2'$ = 277.63

$\delta y_1'$ = 238.99

$\delta l'$ = − 2.23

$$\delta s_1' = \frac{y_1'}{s_1'}\,\delta y_1' - \frac{c'}{s_1'}\,\delta c = -\,97.19$$

$$\delta s_2' = \delta l' - \delta s_1' = 94.96$$

$$\delta T_2' = (w' + \delta w')\,\delta y_2' + y_2'\,\delta w'$$

$$= (2.623)\,(277.62588) + (9812.96)(-0.699) = -\ 6131.05$$

$T_2'' = 26467.62$

$y_2'' = 10090.59$ Sag below upper support

$y_1'' = 9905.09$ $d_2'' = y_2'' - c'' = 336.91$

$k'' = 185.50$ Sag below lower support

$h'' = 4279.00$ $d_1'' = y_1'' - c'' = 151.41$

$c'' = 9753.68$

$l'' = 4317.28$

$s_1'' = 1731.68$

$s_2'' = 2585.60$

$w'' = 2.623$

At 32 deg. fahr. no ice, no wind

$\delta w'' = -\ 0.939$

$$\delta l'' = \frac{\sqrt{(l'')^2 - (k'')^2}}{l''}\left(2\sqrt{\frac{y_1''\, y_2'' + s_1''\, s_2'' - (c'')^2}{2(c'')^2}}\right.$$

$$\left. -\ \frac{h''}{c''}\sqrt{\frac{y_1''\, y_2'' + s_1''\, s_2'' + (c'')^2}{2\,(c'')^2}}\right)\delta c''$$

$$\delta l'' = -\ 0.00722691\ \delta c''$$

$$\delta y_2'' = \frac{\delta l'' + \left(\dfrac{c''}{s_1''} + \dfrac{c''}{s_1''}\right)\delta c''}{\dfrac{y_1''}{s_1''} + \dfrac{y_2''}{s_2''}}$$

$$\delta y_2'' = 0.97662108\ \delta c''$$

$$\delta T_2'' = (w'' + \delta w'')\ \delta y_2'' + y_2''\,.\,\delta w''$$

$$= 1.6446299\ \delta c'' - 9475.0640$$

$$\delta l'' = \frac{l''}{E\,A}\,.\,\delta T_2''$$

$$-0.00722691\delta c'' = \frac{4317.28}{11856000}(1.6446299\ \delta c'' - 9475.0640)$$

$$= 0.00059888\ \delta c'' - 3.4502787$$

$\delta c'' = 440.88562$

$\delta y_2'' = 430.58$

$\delta 1'' = -\ 3.19$

$\delta s_1'' = -\ 20.40$

$\delta s_2'' = 17.21$

$\delta T_2'' = 8749.97$

$T_2''' = 17717.65$

$y_2''' = 10521.17$

$y_1''' = 10355.67$ Sag below upper support

$k''' = 185.50$ $d_2''' = y_2''' - c''' = 326.60$

$c''' = 10194.57$

$h''' = 4279.00$ Sag below lower support

$l''' = 4314.09$ $d_1''' = y_1''' - c''' = 141.10$

$s_1''' = 1711.28$

$s_2''' = 2602.81$

Calculation for various temperatures with no ice or wind loading. Basis 32 deg. fahr. no ice, no wind.

$$\delta l''' = l'''\,\alpha\,\delta t$$

$$\delta c''' = \frac{\dfrac{l'''}{\sqrt{(l''')^2 - (k''')^2}}}{2\sqrt{\dfrac{y_1'''\,y_2''' + s_1'''\,s_2''' - (c''')^2}{2\,(c''')}} - \dfrac{h'''}{c'''}\sqrt{\dfrac{y_1'''\,y_2''' + s_1'''\,s_2''' + (c''')^2}{(2\,c''')^2}}}\ \delta l'''$$

$$\delta c''' = -\ 150.14441\,.\,\delta l'''\quad \delta l''' = -.006660255\,.\,\delta c'''$$

$$\delta y_2''' = \frac{\delta l''' + \left(\dfrac{c'''}{s_1'''} + \dfrac{c'''}{s_2'''}\right)\delta c'''}{\dfrac{y_1'''}{s_1'''} + \dfrac{y_2'''}{s_2'''}}$$

$$\delta y_2''' = 0.97872241\,.\,\delta c'''$$

$$\delta s_2''' = \frac{y_2'''}{s_2'''}\ \delta y_2''' - \frac{c'''}{s_2'''}\ \delta c'''$$

$\delta s_2''' = 0.0394556\ \delta c'''$

$\delta s_1''' = \delta 1''' - \delta s_2'''$

$\delta T_2''' = w'''\ \delta y_2'''$

$\delta T_2''' = 1.6481685\ \delta c'''$

$\alpha = 0.00000662$

$l\,.\,\alpha = 0.02855927$

TEMPERATURE FAHR.

	32 deg.	−20 deg.	0 deg.	20 deg.	40 deg.	60 deg.	80 deg.	100 deg.	120 deg.
δt	0	−52	−32	−12	8	28	48	68	88
$\delta l'''$	0	−1.485082	−.913897	−.342711	.228474	.799659	1.370845	1.942030	2.513216
l''''	4314.09	4312.60	4313.18	4313.75	4314.32	4314.89	4315.46	4316.03	4316.60
$\delta c'''$	0	222.976	137.066	51.456	−34.304	−120.064	−205.825	−291.585	−377.345
c''''	10194.57	10417.55	10331.64	10246.03	10160.27	10074.51	9988.74	9902.98	9717.22
$\delta y_2'''$	0	218.23	134.15	50.36	−33.57	−117.51	−201.44	−285.38	−369.32
y_2''''	10521.17	10739.40	10655.32	10571.53	10487.60	10403.66	10319.73	10235.79	10151.85
y_1''''	10335.67	10553.90	10469.82	10386.03	10302.10	10218.16	10143.23	10050.29	9966.35
$\delta s_2'''$	0	8.80	5.41	2.03	−1.35	−4.74	−8.12	−11.50	−14.89
s_2''''	2602.81	2611.61	2608.22	2604.84	2601.46	2598.07	2594.69	2591.31	2587.92
$\delta s_1'''$	0	−10.29	−6.32	−2.37	1.58	5.54	9.49	13.44	17.40
s_1''''	1711.28	1700.99	1704.96	1708.91	1712.86	1716.82	1720.77	1724.72	1728.68
$\delta T_2'''$	0	267.50	225.91	84.81	−56.54	−197.89	−339.23	−480.58	−621.93
T_2''''	17717.65	18085.15	17943.56	17802.46	17661.11	17519.76	17378.42	17237.07	17095.72
d_2''''	326.60	321.85	323.68	325.50	327.33	329.15	330.99	332.81	334.63
d_1''''	141.10	136.35	138.18	140.00	141.83	143.65	145.49	147.31	149.13

$d_2'''' = y_2'''' - c''''$ Sag below upper support

$d_1'''' = y_1'''' - c''''$ Sag below lower support

A Year's Progress in Lighting

By Committee on Production and Application of Light[1]

THE past year resembles the preceding one, in that the notable advances were those of better and more intensive application of available equipment and methods rather than of fundamental discoveries.

The really outstanding event of the year was a nation-wide campaign of education on home lighting. This activity was conducted by the entire electric lighting industry during the fall of 1924 and represented the most extensive cooperative movement ever undertaken by the electrical industry. Because of its noncommercial character it received widespread endorsement from school authorities, and culminated in an essay contest in which about one million high school pupils competed for valuable prizes.

It is safe to say that, as a result of this campaign, the American public has a better understanding of lighting, especially in the home, and is approaching such problems more intelligently.

In general, lighting has enjoyed a very healthful advance both in extent and quality of application. It has been a year of prosperity to the industry and of enhanced service to the people.

As pointed out in previous reports, the best numerical figures available to indicate the growth of lighting application are in the number of incandescent lamps consumed.

The large incandescent lamps represent the lighting of factories, stores, homes, streets, trains and similar places on circuits of electric service companies, electric and steam railways and other power plants. Of these large lamps, 263 million were sold in 1924, an increase of 7½ per cent over 1923.

The other major class is the miniature lamps of which about two-thirds are used on motor vehicles, one-sixth for flashlights and other small battery lamps, and one-sixth for Christmas trees and similar decorative purposes. Of this class about 188 million lamps were sold, or an increase of 8 per cent over 1923.

These figures are quite conservative, since they indicate only the number of lamps and are not weighted according to the size of lamps. Particularly in the large lamp group there is a tendency toward the use of higher power lamps. Had the measure been in terms of wattage capacity, the increase would presumably have been greater, or if in lumen capacity, still greater. Such figures will soon be available and are desirable for certain kinds of comparison. The simple, numerical figure is, however, suitable for the present purpose.

Illuminants. Present-day illuminants are still far below the scientific ideals of efficiency, and considerable experimental investigation is underway. While favorable indications have been observed, no important practical improvements have been reported.

Frequent minor improvements have been made in incandescent lamps, but these have been mostly in the nature of refinements that do not receive prominent recognition by the users. That the improved manufacturing appliances mentioned in previous reports have brought results, is evidenced by the several reductions in lamp prices. It is also reported that the average quality of the lamps has improved during the year.

A general exposition of the advance of incandescent lamp quality since Mr. Edison's invention was given by J. W. Howell, in his address[2] (on receiving the Edison Medal) at the 1925 Midwinter Convention.

In last year's report mention was made of the tendency toward the use of the ring shaped filament, that is, a helically coiled filament formed into an open ring. More recently there has been a tendency to warp the ring so as to give a higher horizontal component of light.

With the application of incandescent lamps to new uses, there is a constant tendency to multiply the number of special types, bases, and other features, which interfere with interchangeability, increase lamp costs, and often introduce confusion in the selection of lamps, as well as delay in securing them. Lamp Engineers are constantly studying means of simplifying and standardizing. The great advantage of standardization to light users is particularly evident to those familiar with conditions abroad where less progress has been made toward eliminating unnecessary variations.

Considerable experimental work has been done on diffusing finishes for lamp bulbs, with the view of effectively meeting the various demands of lighting practise. Some of these promise real improvement in the near future.

During the past year or two there has been an increase in accuracy of incandescent lamp manufacture, particularly in the focus types where small tolerance of light center length is important.

The automobile rear lamp has been raised from two to three candlepower and improved in efficiency. Experiments have been made with automobile headlight lamps, having two equal power filaments, to produce a suitable dipping of beam by switching from one filament to the other. Much experimental work

1. Annual Report of Committee on Production and Application of Light.

G. H. Stickney, Chairman		
W. T. Blackwell,	F. F. Fowle,	F. H. Murphy,
J. M. Bryant,	G. C. Hall,	Charles F. Scott,
W. T. Dempsey,	H. H. Higbie,	B. E. Shackelford,
H. W. Eales,	A. S. McAllister,	W. M. Skiff,
F. M. Feiker,	P. S. Millar,	C. J. Stahl.

Presented at the A. I. E. E. Annual Convention, Saratoga Springs, June 24, 1925.

2. See A. I. E. E. JOURNAL, March 1925, p. 310.

has been carried on for the Government and others to adapt the incandescent lamp to the various requirements of night flying, and considerable improvement has been made during the year.

Candle Power Standard. A remarkable research extending over several years and reported in 1924, culminated in a proposal of a primary standard of candle power. All previous primary standards have been so subject to variation for one cause or another, as to be too inaccurate for standardizing purposes. In 1910, the United States Bureau of Standards cooperated with the English and French National Laboratories in establishing the international unit of candle power recorded in the construction of incandescent lamps. No other method compared with this for accuracy. The desirability of an absolute standard, which can be reproduced from specification and which will avoid any possibility of drift, is obvious. While it is too early to say absolutely that this has been accomplished, the indications are that it has. The standard device consists of a cylindrical platinum fuse with a longitudinal slit. This is supported by conductors at both ends and heated by an electric current. A certain section of the interior as viewed through the slit has been found to follow the "black body" law, and readings are taken with increasing temperature up to the point where the platinum melts, blowing the fuse. In other words, the method measures the light emitted by a black body at the melting point of platinum, a condition which has been regarded as most likely to give a suitable primary standard.

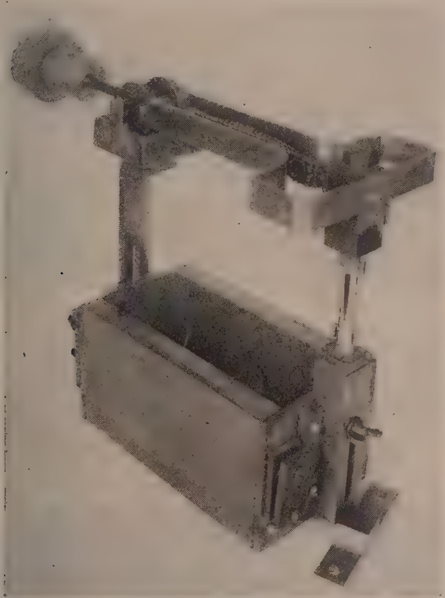


FIG. 1—NEW PRIMARY STANDARD OF CANDLE POWER PROPOSED BY DR. H. E. IVES

Device for producing black body radiation at melting point of platinum showing slitted cylinder of platinum and support. (See text.)

Lighting Practise. No radically new devices have come out. The general tendencies recorded in last year's report have continued. In commercial lighting, the shallow enclosing globe has seemed the most popular, although there has been a growing use of certain forms of indirect and semi-indirect units, especially in the highest grades of installations where accurate vision is important.

In the interest of eyesight conservation it is gratifying to note the continuing spread of appreciation of the need of good lighting in schools. This will no doubt be stimulated by the new American Engineering Standard Code of School Lighting. There is still a serious economic resistance, and it is still true that when daylight fails, the student is less adequately cared for than the office worker. Nevertheless the year has witnessed a large increase in the number of reasonably adequate installations.

Store window lighting has been a field of increased activity. The data referred to in last year's report have apparently been effective in convincing merchants of the sales value of light. Colored light and spot lights are being extensively used and are making the merchandise more interesting to look at. In the business sections, the practise of providing strong illumination in the daytime for the purpose of eliminating external reflections or rendering the displays more effective, has grown rapidly.

The advance in levels of window lighting is indicated by the fact that equipment manufacturers have found it desirable to develop and market reflectors for 300- and 500-watt lamps, whereas a year ago the reflector for 150-watt lamps was the largest in common use.

In industrial lighting the steel dome, because of its economy, coupled with moderate diffusion, is still the most common equipment, but in many processes a combination glass and steel unit, and the various forms of opal and prismatic globe equipments, are being preferred because of their greater diffusion. Illumination levels are still being raised. After a survey of the situation the electric lighting industry has concluded that the time is ripe for increased activity in the industrial field, and an extensive campaign is projected for the fall of 1925.

Home lighting is more essentially an artistic problem than an engineering problem. However, certain engineering and utilitarian features are deserving of more attention, and it is important that artistic considerations include the lighting effect as well as the design of the equipment. The trend of practise is toward better diffusion and more illumination, avoiding what has been aptly termed "glare and gloom."

The use of portable lamps is spreading rapidly, with an increasing use of those which direct considerable light to the ceiling, for redirection. Portable equipment has certain features of flexibility which permit the exercise of personal taste. It is also becoming quite common for housewives to make their own shades.

While some of these are not particularly effective, they permit a rather free expression of personal taste and improvements may be expected through a better understanding of the possibilities. The best practise for general rooms usually requires a combination of fixed and portable equipment, and it is desirable that wiring should be planned to accommodate both types.

FIG. 2—SIGN LIGHTING, SHOWING ONE OF THE WORLD'S LARGEST SIGNS ON BROADWAY, NEW YORK

The upper sign employs nearly 20.000 incandescent lamps.

The kitchen lighting movement which was reported as very active last year has been less conspicuous, in contrast to the educational movement of 1925. Nevertheless it is probable that the number of improved installations in kitchens has continued to increase.

Electric Light Wiring. One of the problems confronting the engineers who are endeavoring to improve lighting practise is the tendency to stint in the wiring of buildings and fail to provide outlets in locations necessary to produce suitable illumination. In order to call attention to this question and encourage better provision, a so-called "Red Seal" campaign has been instituted under the direction of the Society for Electrical Development and installations complying with an accepted standard are indicated by a red seal.

The progress in the application of the elexit or disconnecting support for lighting units has been somewhat disappointing, in view of the inherent advantages of such a scheme. They are being found exceedingly useful in luminaire display rooms, and it is probable that such use will stimulate their application elsewhere.

Outdoor Lighting. Larger and better things are being done in sign lighting and the use of higher power lamps which was formerly confined to a few important centers, is becoming common in smaller cities and less central locations. To what an extent illuminated advertising is contributing to the illumination of metropolitan business districts can only be appreciated by visiting those sections at the very late hours when it has ceased to function. By contrast, the regular street lighting seems surprisingly faint. One large sign installed in 1924 contained 19,000 lamp sockets.

Colored floodlighting, especially in connection with flashing effects, is finding considerable application, both for advertising signs and for buildings.

Street Lighting. Street lighting has been quite active during the year. It is estimated that the new and replacing installations of 1924 required about fifteen per cent more equipment than those of 1923, which in itself had shown quite an advance. The vast majority of these installations utilize the gas-filled tungsten lamp.

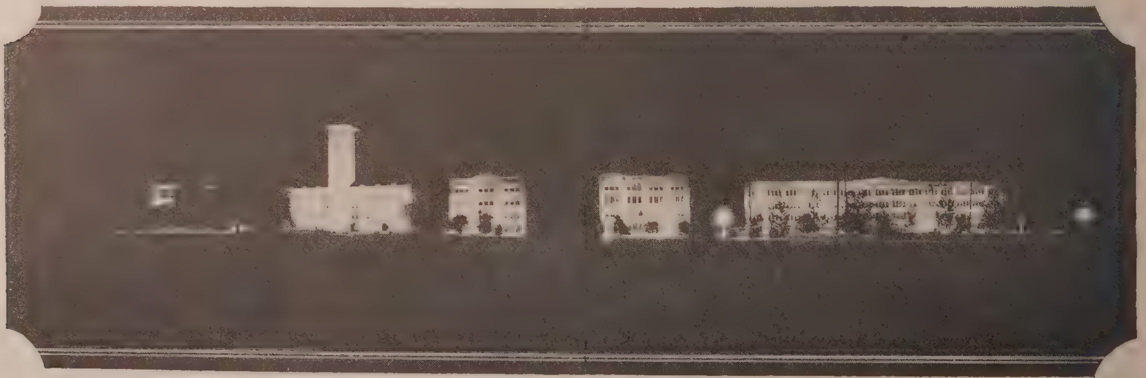


FIG. 3—FLOODLIGHTING FOR PUBLICITY PURPOSES

A large playing card factory at Cincinnati has one of the largest of the recent installations. Eight 500-watt floodlights illumine the tower, twenty four 1000-watt floodlights light the facades facing the camera, and eight more are projected on surfaces facing in another direction and therefore not shown.

There have been minor improvements in transforming and other accessory equipment, as well as a few improved designs of luminaires.

The trend is still toward the ornamental units and poles. Twin units have been used to some extent in

white-way lighting, although these are usually less economical than the single higher power unit.

Recent statistics on the sale of series incandescent lamps indicate that over 60 per cent are of 1000 lumens or less. In the opinion of engineers who have made general analysis of street lighting costs this percentage is too high and better economic conditions would exist if larger lamps were being used. This is based on the principle that the cost of service increases much less rapidly than the volume of light. The tendency is in the right direction, but greater progress is desirable.

FIG. 4—THE BOARDWALK

Atlantic City has, in some sections, to be illuminated from one edge only. Specially devised ornamental units direct the larger portion of the light across the walk and still provide a lower illumination on the beach without shadows on the globes. Width of walk 60 ft., spacing of posts 70 ft., size of lamps 750-watt. Photo taken late at night after sign and show window lights were extinguished.

Each unit is arranged so that light from a 200-watt lamp symmetrically directed can be switched on.

In residence and other secondary streets, the asymmetrical types of distribution seem to have proved their worth. Some discussion is still going on as to the merit of various characteristics of asymmetrical distribution, and it is probable that the next few years experience will bring out a better general understanding as to the types and degrees suited for different street lighting problems.

Asymmetrical lighting of highways, utilizing equipment designed to deliver the maximum illumination on the road surface is meeting with considerable success, and promises to provide the best solution for the problem of handling heavy night traffic on important roads.

Extensive experimental studies preliminary to establishing improved street lighting have been underway in a number of cities, notably Indianapolis, Indiana; Columbus, Ohio and St. Louis, Missouri. It is reported that the investigation in Indianapolis has led to a decision to install a new unified system through that city.

During the year, a cooperative study of urban street lighting was made by a committee appointed jointly by the New York State Conference of Mayors and other City Officials and the Empire State Gas and Electric Association. This committee has made a constructive recommendation regarding practises to be followed and standards of lighting to be adopted for various classes of streets.

A general committee of the National Electric Light Association has been studying the problems of street lighting and is preparing a report which should be of considerable value.

Still other street lighting activities are underway, and studies by simultaneous comparison in demonstrations are being made. With the existing need and the widespread study of the various problems, it is probable that the next few years will witness a rapid advance in this field.

Traffic Signal Lighting. Closely associated with street lighting is the traffic signal lighting. This falls in two main classes.

The flashing traffic beacons which merely warn of an intersection, are placed at moderately congested points of cities, towns and interurban roads. Electric signals of this sort are being installed in considerable number.

The second group is the traffic control signals for controling the movement of traffic in congested districts. It has been found expedient to synchronize the various signals of each district, and to extend the system some distance beyond the points of traffic congestion. Not only does this sort of a system reduce accidents by speeding traffic, but it reduces the congestion, not to mention the convenience resulting to the motorist. A considerable number of such installations have been made during the past year and many others are projected.

FIG. 5—HIGHWAY LIGHTING—PLEASANTVILLE BOULEVARD, ATLANTIC CITY, ILLUMINATED WITH 2500 LUMEN (250 C. P.) LAMPS IN UNIT DESIGNED TO CONCENTRATE LIGHT ON ROADWAY

Units about 25 ft. high, spaced one for each 225 ft. of road, staggered. Central motor way, glossy surface, about 28 ft. wide, wagon way on each side about 15 ft. wide.

A notable example is that on Broadway, New York City, from Rector Street to 86th Street, a distance of six miles. This system contains a number of new and interesting features. It is arranged so as to avoid obstructing the roadway and requires only six police officers for its operations, where an earlier form would have required at least twenty-six. Moreover, these officers are on the street level and so quickly available for emergencies. A parallel system is about to be installed in Seventh Avenue.

FIG. 6—TRAFFIC SIGNAL LIGHTING

New installation on Broadway, New York, showing arrangement for locating signals conspicuously over line of travel without obstructing traffic.

Other Practises. Lighting practises in the operation of railroads are extending rapidly. While floodlighting of railway classification yards is not new, recent investigations have brought about a considerable extension of such lighting and a more definite crystallization of the practise. The Association of Railway Electrical Engineers is undertaking the preparation of a comprehensive manual of railroad lighting practises.

Electric lighting is contributing much to the facility and safety of surgical operations. Much better lighting is being provided in some of the leading operating rooms, and various small lamps are playing an important part in lighting internal organs. Although not new during the year, there appears to have been but little mention in engineering circles of an instrument for entering the stomach or lungs through the mouth. By the light ot the smallest lamp made, it is possible to examine the walls of these organs, remove foreign matter, such as tacks or pins, and perform other operations in the saving of life.

In the newer applications of artificial light, such as night flying, plant growth control, the use of polarized light to study internal strains of structural forms, considerable progress has been made.

Education. Educational work has been carried on extensively. Besides a number of classes which have been operated by various organizations, notably the incandescent lamp manufacturers, an extensive course to train illuminating engineers for electric service companies was operated jointly by the Illuminating Engineering Society and the National Electric Light Association. This group of students came together in Chicago, visited South Bend, Detroit, Cleveland, Washington, New York and vicinity, Boston and Lynn. Lectures were given in Cleveland, New York and Harrison and representative illuminating engineering departments were visited and studied.

Another large lighting demonstration has been opened since the beginning of 1925 and in a number of European cities, demonstrations have been patterned after the American practise. The European activity in this field has no doubt been considerably stimulated by American engineers who have been abroad during the year, and several of whom presented important papers on lighting practise at the Geneva meeting of the International Commission on Illumination.

FIG. 7—RAILWAY CLASSIFICATION YARD LIGHTING

An installation partly completed at Selkirk, N. Y. which employs nearly 100 floodlights, 1000 watts each, projecting light along the road in both directions.

At this meeting, the commission which has in the past centered its attention on standards, and highly technical phases, decided to place more emphasis on practise and applications. The 1927 meeting is scheduled to be held in the United States.

During 1924, the State of Washington adopted an industrial lighting code, making the tenth state to take such action. These ten states represent a population of about 42,000,000.

The revised School Lighting Code, initiated by the Illuminating Engineering Society, has become an American Engineering Standard under the joint sponsorship of the American Institute of Architects and the Illuminating Engineering Society.

Industrial Lighting Tests. It has been generally assumed that good illumination was warranted economically through its influence in speeding production. Data supporting this view has been accumulating for several years. The National Research Council is undertaking an extensive series of tests, which when completed should provide authoritative figures over a range of representative industries. The Council is undertaking to study the welfare aspect as well as the economic. Because of the extent of the problem as well as the thoroughnes of the methods, the results are not expected to be available for at least another year.

Committee Activity

The Committee on Production and Application of Light is composed for the most part of members who are widely separated geographically.

This is suitable for the general work of the committee but precludes full attendance at meetings. As a result, after the original organization meeting each year, practically all business has been conducted by correspondence.

The organization meeting for the current year was held at A. I. E. E. headquarters, October 9, 1924, three members being in attendance. Because of this small attendance, the Chairman submitted the minutes to the entire committee for comment before considering the action final. No criticism was received.

The committee organization of last year was retained; Dr. B. E. Shackelford being detailed to solicit papers for conventions, Mr. W. M. Skiff being retained in charge of securing Illumination Items and fillers for the A. I. E. E. Journal and Mr. G. H. Stickney was asked to supervise the preparation of the Annual Report. It was decided to continue previous policies and plans.

Later in the year the question of representation on the Standards Committee came up and was handled by correspondence. Since the Chairman was already attending the meetings of that committee in another capacity, it was considered expedient that he represent this committee.

Illumination Items. Because of the relation of the Institute membership to the lighting art, this has seemed to provide the best method of presenting a larger part of the lighting material to the organization. Throughout the year, the Editor of the Journal has been kept supplied with items in advance of his requirements in ample quantity to fill all of the space which he deemed it expedient to devote to this subject.

Convention Papers. Considering the state of the art and the interests of the membership, the committee has not considered it expedient to place many papers on the convention programs. Two papers have been arranged for presentation at national conventions during the year, viz., "Street Lighting—A Municipal Problem," by Rich D. Whitney—Pacific Coast Convention, Pasadena, October, 1924, "Automotive Headlighting," by J. H. Hunt,—St. Louis Convention, April, 1925.

Preliminary arrangements are underway for securing several papers for future conventions. A paper had been arranged for the regional meeting at Cleveland, but has been held in abeyance since the withdrawal of this meeting.

Cooperation with Branches. No convenient means seems to be yet available for cooperating with Branches. The Chairman has been informally experimenting, not in the name of the Institute, with one university in the hope of arriving at a plan. A course of lectures was arranged and is now being carried out. At the termination of this course, it may be possible to draw some conclusion as to its effect. A subcommittee under the chairmanship of Prof. H. H. Higbie has been studying the problem, and it is hoped that a report will be received in time to be of assistance to next year's committee.

Lighting Publicity. A system is in vogue whereby members of the committee reviewing original Illumination Items indicate other publications likely to be interested in the material, whereupon the Editor of the Journal undertakes to furnish proof of article to the designated periodicals with release dates.

In conclusion, the Chairman wishes to acknowledge the cordiality which has been extended to him by the entire committee, and especially the active cooperation of those members who have assumed the specific tasks already mentioned.

A NEW REFLECTOR DEVELOPED

A new reflector that is as efficient as a freshly silvered glass mirror, that will not tarnish nor corrode when exposed continually to the weather, and so hard that the surface can be cleaned with gritty waste without scratching, was described by Dr. Robert J. Piersol, research physicist of the Westinghouse Electric & Manufacturing Company, in a paper read before a recent meeting of the Illuminating Engineering Society meeting at Detroit.

The new reflector has a surface of polished chromium, and was developed by Dr. Piersol in his search for one that would be satisfactory for use on automobile headlights and outdoor flood lights. Glass backed with a silver coating is extremely fragile and costly.

Aluminum and its alloys and other metals have been tried and found to be of little value. The reflectivity of chromium is selective to about the same extent as silver. It is doubtful if the ordinary observer would be able to distinguish between the two. Therefore, the color is pleasing. The coefficient of reflection is initially high and remains high throughout an accelerated life test.

Chromium is not subject to corrosion from sulphur fumes on water vapor, which causes tarnishing in silver. It is attacked only by chlorine fumes which are of very rare occurrence in the atmosphere.

Discussion at Spring Convention

SYNCHRONOUS-MOTOR DRIVE FOR RUBBER MILLS[1]

(DRAKE)

ST. LOUIS, MO., APRIL 17, 1925

S. H. Mortensen: Mr. Drake's paper recognizes the importance of the application of dynamic braking to motors driving rubber mills and similar industrial installations where quick stops are necessary for safety reasons. The importance of this was brought to the speaker's attention in 1918, in connection with the design and operation of a 500-h. p., 450-rev. per min., self-starting synchronous motor, geared to a four-roll rubber-mill drive in the plant of the B. F. Goodrich Company in Akron, Ohio. This motor was installed for power-factor improvement and as it replaced a wound-rotor induction motor, it was connected to the mill by means of the magnetic clutch which formed part of the original motor drive, together with a solenoid-operated brake for stopping the mill in case of accident. As this installation was a novelty at that time, extensive tests were made on this motor. These proved not only its suitability for this type of drive but

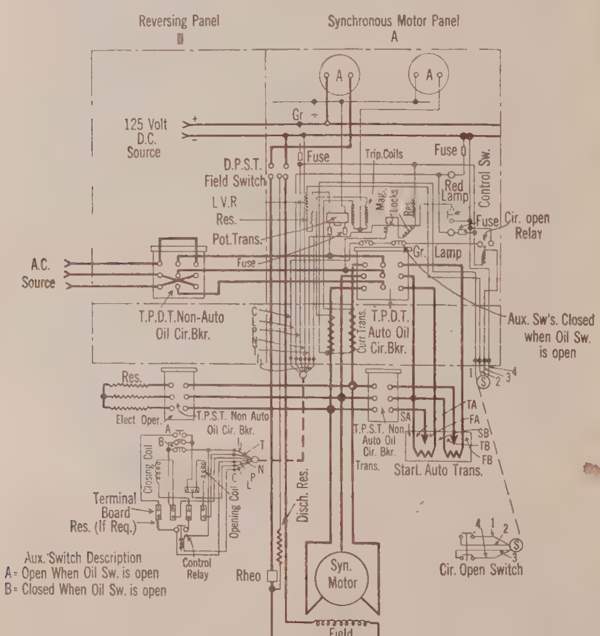


FIG. 1—DIAGRAM OF CONNECTIONS AS SEEN FROM REAR OF PANEL. ALL SECONDARY WIRE NO. 12 R. I. F. P.

also that it did have ample starting torque to bring the mill up to speed with the clutch energized. Its pull-out was beyond any load that could be put upon it by overloading the mills with the toughest rubber available.

The first opportunity for applying dynamic braking in conjunction with a synchronous-motor rubber-mill installation occurred in 1920, when two 500-h. p., 450-rev. per min. synchronous motors were designed for direct gearing to two four-roll, rubber-grinding mills in the plant of the Fisk Rubber Company, Cudahy, Wis. In this installation the magnetic clutch was omitted from the mill drive, together with the mechanical brake, the motors being designed with a heavy squirrel-cage winding proportioned to develop a starting torque of 2.3 times full load torque which enables it to start the fully loaded mills from rest and bring them up to synchronous speed. The motor was designed for dynamic braking. To stop the mills a safety switch ocated over the rolls is tripped and this automatically disconnects the fully excited motor from the power supply and short circuits its armature winding through a resistance, thereby producing the braking effect. The type of control used is shown in Fig. 1, herewith. This installation is to the best of the speaker's knowledge the first where the driving motor is geared direct to the mill and dynamic braking is used for emergency stopping. After these motors had been in service for a considerable length of time they were subjected to a number of tests and

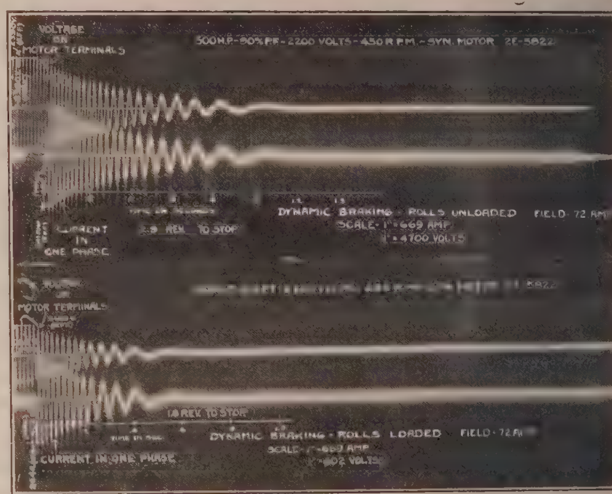


FIG. 2

the result of these tests together with a description of the general installation was written by the speaker and published in the August 4th, 1923, number of the *Electrical World*.

Fig. 2 is an oscillographic record of the voltage and currents obtained at the terminals of this motor during the period of dynamic braking. The upper records show that the time required from the instant the safety switch was operated to the time the empty mill came to a stop corresponds to 2.9 revolutions

FIG. 3

on the 450-rev. per min. motor. As the gear ratio on this mill is 1 to 20, the mill rolls actually came to a stop in 0.145 revolutions. The lower record of Fig. 2 shows the same condition as the upper part except that the mills were loaded when this test was made. Under these conditions the motor came to a stop in 1.8 revolutions. By making simple adjustments this stopping time could be further reduced.

Comparative tests were made on mills similar to the one described above, except that they were driven by induction motors through a magnetic clutch and stopped by disconnecting the magnetic clutch and setting the mechanical brake on the mill side

1. A. I. E. E. JOURNAL, April 1925, p. 350.

of the drive. In all cases it was found that the dynamic braking was superior to the mechanical braking. It is consistent in value and acts more quickly than the mechanical brake and with less mechanical shock to the mill parts. The rapidity with which the rolls of a mill can be stopped by means of dynamic braking depends upon the stored energy of its rotating parts, the time elements of the switches, the characteristics of the motor and the amount of resistance connected in the armature circuits during braking. When the resistance is adjusted to give a maximum braking effect, the initial torque during dynamic braking is comparable to the pull-out torque of the motor with unchanged excitation. On the high-speed, gear-type synchronous motors the braking effect is as a rule ample to stop the mills in as short a time as the strain in the mechanical parts involved will permit, but where slow-speed direct-connected synchronous motors are involved the dynamic braking torque may not be sufficient to stop the mill in the desired time. In such installations the braking effect can be further increased by increasing the motor excitation simultaneously with its being disconnected from the line.

In connection with the installation described in Mr. Drake's paper, I should like to ask how this mill is stopped in case it becomes necessary to bring it to a sudden stop during the starting period, prior to the time when excitation is supplied to its fields.

In conclusion it may be of interest to the members of the American Institute of Electrical Engineers to know that dynamic braking has found successful application in connection with synchronous-motor-driven steel-rolling mills. An installation of this kind is shown in Fig. 3, which depicts a synchronous-motor-driven roughing mill. In this installation the dynamic-braking feature has proven its value as a safety measure and the rapid stops which it insures have, in several instances, either eliminated or minimized accidents which otherwise might have proven fatal to human life.

F. A. Hoener: The writer is connected with the Firestone Tire & Rubber Company; as engineer, also chairman of the Engineering Committee, Rubber Section, National Safety Council. We are collating data with reference to stopping distances on rubber mills and I am, therefore, very much interested in this discussion. In this connection I have come in contact with state commissions and have discussed with them the merits of the magnetic clutch brake and synchronous motors for stopping mill lines. One item which the synchronous-motor manufacturers have overlooked and which the state officials are giving not a little consideration is, what happens when the power goes off? We have had accidents due to power interruption on the part of the public utility or trouble in our own main power house causing power and lights to go off at the same time and mill men working on mills have been caught in the bite of the rolls. In cases of this kind dynamic braking does not do much good. We realize this is a very remote accident hazard, however state industrial boards think along these lines.

Another item to be considered is the changing over of existing equipment. I am interested in getting some of the rubber manufacturers in the United States to change their present equipment in such a way that it will become reasonably safe. It is hard to realize that there are rubber mills in existence which have only a motor direct-connected to the mill line without a brake or other safety device. This results in the line coasting to a stop after the power has been shut off. We also realize that when the manufacturer is making a new installation, he will seriously consider the installation of a synchronous drive on account of power-factor correction. However, this does not help out the manufacturer who desires to change over existing equipment in order to cut down the length of stop.

We have in Akron, particularly at Firestone, some very large mill lines direct-connected to 800-h. p. induction motors by means of magnetic clutch brakes. I shall grant that the stopping distances so far obtained on these lines have not been very good. The chief trouble has been in demagnetizing the clutch. In other words, the mechanical brake has to help overcome the magnetization that stays in the clutch. We, along with the manufacturers of equipment, have been working for some time to overcome this trouble.

A great deal has been done in correcting faulty equipment although there is a great deal still to be done. Mills, in my opinion, offer one of the greatest hazards in the rubber industry because it is impossible to guard the bite of the rolls and still have them do the job for which they were installed.

Quentin Graham: The performance of a synchronous motor when used for dynamic braking, as described by Mr. Drake, can be predicted with reasonable accuracy in a fairly

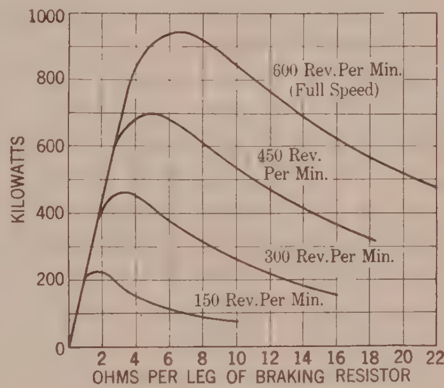


FIG. 4

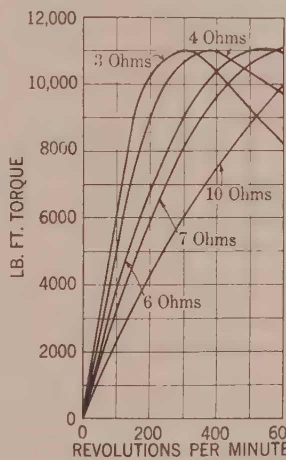


FIG. 5

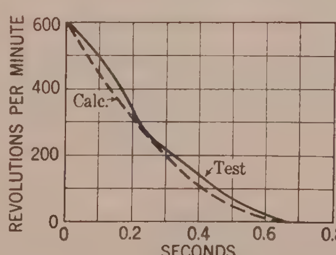


FIG. 6

simple manner. During the braking period, the motor becomes a generator feeding a non-inductive load. The energy of rotation of the machine and its load is converted into heat which is dissipated mainly in the external braking resistor. Since the

output of the machine as a generator is kept at unity power factor, the maximum braking effort is produced for a given current. This is a decided contrast to the braking performance obtained with induction motors when reversed voltage is applied and the power factor and torque per ampere are quite low.

It is interesting to note the effect of changes in the ohmic value of the braking resistor. The curves in Fig. 4 show the variation in kilowatt output with changes in the braking resistance for a particular motor. Fig. 5 shows the corresponding values of braking torque determined from the kilowatt output curves. The losses within the motor, which also have a retarding effect, were neglected in plotting these curves since they are relatively unimportant. An inspection of the curves in Fig. 5 shows that at about 4 ohms per leg the braking torque would be most effective. Fig. 6 gives calculated and test curves showing the rate of retardation of the motor. For the case shown here the maximum braking torque was between two and a half and three times full-load torque.

For the retardation of heavy inertia loads which require much longer periods of time, there are two refinements of control which are used. First, the field current is increased to the maximum value so as to give the greatest possible output of the motor. Secondly, the braking resistance is varied as the speed decreases so as to obtain maximum output at all speeds. For most applications of dynamic braking, however, the retardation is too rapid to justify the use of these added complications.

P. C. Jones (communicated after adjournment): Mr. Drake's paper brings up a subject which should have been given more attention before, not only because it pertains to a distinct change in industrial drives but because the general use of such a method would vitally affect the entire central station industry by its decided affect on system power factor.

Thus, while there are any number of phases of the subject that could well be discussed, there are just two points I wish to bring up—both of them referring to the use of synchronous motors for dynamic braking.

It has always been recognized that braking equipment, particularly if used for emergency purposes, should be independent of any external source of energy. For this reason electrically operated brakes have been arranged so that the magnet, solenoid, or motor as the case may be, holds the brake released and a spring or weight sets the brake. Thus, even though the power should fail at the time the safety bar was pulled there would be no failure to stop. This principle is violated to some extent in the use of a synchronous motor as a dynamic brake. Where a direct-connected exciter is used the issue is met part way but not completely.

Of course, the chances of a power outage occurring at the time of braking are remote and generally will not be a sufficiently strong counter argument to have any appreciable weight in the ultimate conclusion, but they should always be considered if for no other purpose than to insure reliable excitation.

The second weakness I want to point out is inherent in all dynamic braking schemes. The stopping of a motor under a purely dynamic effect follows an exponential curve and is asymptotic to the axis of zero speed. Under pure dynamic effect, therefore, a motor will never stop. The expression for velocity is,

$$v = v_0 e^{-\frac{KT}{IZ}} \qquad \textbf{(a)}$$

where v is the speed of the motor at any moment, v_0 its initial speed, K a constant, I the moment of inertia of the system, and Z the impedance of the braking circuit.

In any actual case, however, in addition to the dynamic action there is a certain amount of line and motor friction and windage. Under this influence the velocity expression changes to the form below:

$$N v_0 = (N v_0 + 1)\, e^{-\frac{KT}{IZ}} - M \qquad \textbf{(b)}$$

If the expression (**a**) is integrated to obtain the distance traveled before stopping, the result will be infinity, but the expression (**b**) may be so integrated and yields a result in the form below:

$$s = (P\, I / Z) - Q \qquad \textbf{(c)}$$

P and Q are constants, s the distance traveled before stopping, and I and Z bearing the same significance as above. Actually both (**b**) and (**c**) are modified by armature reaction which cuts down the initial torque and thus decreases the initial rate of deceleration, and, in the case of an a-c. generator, here being discussed, by the decreasing frequency which, by decreasing the reactance drop, has an opposite affect.

There is never any question as to the satisfactory stopping of a synchronous motor-driven mill line by dynamic braking under load conditions. Under unloaded conditions, however, where the friction load is low and the moment of inertia is high, and a very quick stop for safety purposes is desired, the conditions should be carefully checked.

Hans Weichsel (communicated after adjournment): It appears that the great number of applications to which the synchronous motor has proved to be useful, contradict the statement made by one gentleman that the synchronous motor cannot be considered as a machine of the future but rather one of the past.

It is interesting indeed to see from Mr. Drake's paper that the synchronous motor has been successfully used to replace induction motors with wound secondary, which, up to the introduction of the synchronous motor, had been used for this class of service on account of its superior starting characteristics. The operating results have shown that the synchronous motor can perform this work not only as well as an induction motor but has proved to be, in many respects, superior to it. There are two pronounced advantages obtained by the application of the synchronous motor, viz:

1. The power-factor correction.
2. The possibility of applying dynamic braking.

Referring to power-factor correction, the author properly calls attention to the fact that the obtainable correction is not equal to the leading component of the synchronous motor but equal to the sum of the lagging component of the replaced induction motor and the leading component of the replacing synchronous motor. This is a fact which quite often seems to have been over looked in considering the field of usefulness of synchronous motors.

Referring more particularly to the contactor arrangement for obtaining the dynamic braking, the author states that the "voltage generated during braking is utilized to energize the lower magnet and hold the lower contacts together until the motor stops." No reason is given by the author why the voltage and not the current is used for this retaining action. I should think that in all possibility the decision was based on the following two points:

1. Mechanically, it is easier to arrange for a voltage coil than for a current coil.

2. Under the conditions existing during the braking period, the magnetism produced by a voltage coil is nearly constant for all speed conditions, while the magnetism produced by a current coil would decrease approximately proportionally with the decreasing speed.

It will be interesting to hear from Mr. Drake if these are the reasons which governed him in deciding for a voltage coil.

There are a few other questions which I should like to ask in this connection. A statement is made that, for maximum possible safety, the dynamic braking control should be "operated by gravity and not depend upon closing a contactor electrically." It would be interesting to have this statement explained more in detail. It appears to me that an electrically operated contactor is just as safe as a contactor operated by gravity as long as electric supply is in existence, but if the electric supply gives out, the dynamic braking effect fails no matter whether the contactor is

operated by gravity or by electric means, because the possibility is very great that, with failure of the a-c. supply voltage, the d-c. supply voltage for exciting the synchronous motor also fails. Therefore, the braking effect in such an abnormal case would be zero no matter whether gravity or electric control is used for the contactor.

This reasoning assumes that the d-c. exciter is not directly connected to the synchronous motor, but is driven by an auxiliary unit. From the photographs and oscillograms given in the paper, it appears that this assumption is justified.

The very short time required for bringing these mills to a rest by aid of this dynamic braking equipment is extremely interesting, especially in connection with the fact that the current values in the primary winding when braking are materially less than when starting under average conditions. Naturally this is readily explained, because in starting, the motor has to overcome the inertia torque plus the torque necessary to move the rubber through the mills, while during the braking period, the generator torque plus the torque to move the rubber through the mill is equal to the inertia torque. It would be interesting to hear from Mr. Drake how often, under average working conditions, use is made of this dynamic braking equipment. It would seem that the number of braking periods during a day are so few and the time required for the actual braking so short that the braking conditions can be entirely neglected in selecting the frame size of the synchronous motor for a given horse power capacity.

E. W. Pilgrim (communicated after adjournment): It is my belief that dynamic braking of synchronous motors is by far the best method of emergency stopping for this type of motor. Tests we have made check with the data submitted in Mr. Drakes's paper and indicate that there are no severe strains imposed upon the motor or machine and I believe that this system which as far as I know is employed only in rubber mills, will become more or less the universal method in other industries.

Stopping by dynamic braking is always of the same value, whereas stopping by means of mechanical brakes is not, due to the fact that the brakes are not always in perfect adjustment. There is a definite resistance value for stopping the motor in the shortest time, and by varying this resistance, the time can be lengthened. We have found from experiments that increasing the resistance will lengthen the time and also decreasing the resistance over this definite value will also increase the length of time required for stopping.

I much prefer the automatic control as I believe that the mechanical control does not include all the features that should be included, and is not nearly so fool-proof. With hand control, if the operator throws the starting compensator into the starting position and the motor does not start, he is very apt to pull the compensator back to the "off" position which will cause severe arcing on the switch and perhaps its total destruction. The equipment should embrace a relay operated by the field current of the motor so that if the motor loses its field, it will stop. This would indicate to the operator that something was wrong and the trouble could be corrected. Otherwise, an emergency stop might be required when there is no field on the motor, in which case the dynamic braking would not be affective.

I do not think that it is absolutely necessary to operate the dynamic-braking contactors by gravity inasmuch as an electrically operated contactor functions fully as well and I can see no objections to this type of contactor, but the control should have other safety relays for stopping the motor in case of loss in field or loss in voltage. The chances that emergency stopping would be required at an instant when voltage fails, are very remote and I do not feel that it should be considered serious.

Dynamic braking of synchronous motors will, no doubt, be used very extensively now that experiments conducted by various electrical manufacturers have proven its reliability.

A. S. Rufsvold: The early synchronous motor dynamic braking installations described by Mr. Mortensen, are of considerable historical interest. Like any other electrical development, the scheme of control for dynamic braking has been considerably improved since it was first used.

In explaining the oscillograph records which he presented, Mr. Mortensen stated that the time required for the operation of the control immediately preceding the braking action was "very short." The length of this time interval is of vital importance, because during the preliminary functioning of the control, the motor is traveling at full speed. In the apparatus described by Mr. Drake, this time interval is reduced to a minimum value of about 1/20 sec. by the use of a specially constructed contactor. This is an improvement over that type of control which depends upon the opening of one contactor and the closing of another by the use of relays, all of which takes up a considerable interval of time, and is less safe.

Mr. Mortensen has asked what provision has been made in the control described by Mr. Drake for dynamic braking during the starting period, before the excitation has been applied. On the latest type of control, this has been taken care of by arranging the control to automatically apply the excitation when a safety switch is opened during the starting period.

Mr. Hoener mentioned the possibility of the failure of power at the same instant a man is caught in the mill rolls. Although this is an exceedingly remote possibility, yet it is a point which is considered by safety committees. In the control described by Mr. Drake, since the dynamic braking contactor operates by gravity, failure of the a-c. power would not interfere with its operation. Of course, the braking action depends upon maintaining the field excitation, but should the main plant circuit breaker open, there is sufficient energy stored in the rotating parts of the motor-generator set supplying the direct current to maintain excitation during the brief dynamic braking operation. This brings up the question of what would happen in case a direct-connected exciter were used with the motor. On first thought it might be expected that no braking would be obtained, but tests have shown stopping distances quite comparable to those obtained by using separate excitation.

C. W. Drake: Mr. Hoener, Mr. Jones and Mr. Weichsel seem to be under the impression that no dynamic braking is obtained if the a-c. supply fails. This may be true with some types of control, but with the construction described, the failure of a-c. voltage automatically releases the upper contactors and the lower ones are closed by gravity. The d-c. field is maintained because any rotating d-c. machine, such as a motor-generator set or a synchronous converter, will, upon the failure of the a-c. supply, maintain its d-c. voltage for a sufficient length of time to give dynamic braking.

Mr. Jones, in his mathematical discussion, indicates that the synchronous motor losses and friction may materially affect the results of the various equations. He also states that for a quick stop with no load, such calculations should be carefully checked. Tests made on the stopping of synchronous motors in the factory with no load whatsoever indicate that there is no tendency for the motors to coast or drift at low speed. Fig. 6 in Mr. Graham's discussion shows a retardation curve under such conditions and it will be readily appreciated that the addition of a gear unit and mill line will add friction which will still further tend to eliminate drift.

Mr. Weichsel asks why a voltage, instead of a current coil, is used on the lower contactor for holding it closed during braking. The principal advantages of a voltage coil are as follows:

1. Easier to wind and connect
2. Fewer coil designs required to cover all applications
3. Gives more nearly uniform pull, since the impressed voltage and frequency decrease in proportion

Mr. Weichsel also questions the advantages of the gravity-

operated contactor and quite definitely states there would be ny braking in case of power failure. We have already explained who braking is obtained under these conditions and practise has proven it. Another advantage of the gravity-operated contactor is that any break in the control wiring immediately shuts down the mills, while if any circuit has to be made during the braking cycle, a failure in that wiring would remain unnoticed until it was required to operate.

Discussion at Swampscott Meeting

TAP CHANGING UNDER LOAD
(Albrecht)
VOLTAGE CONTROL OBTAINED BY VARYING TRANSFORMER RATIO
(Blume)[1]
CHANGING TRANSFORMER RATIOS WITHOUT INTERRUPTING THE LOAD
(Bates)

Swampscott, Mass., May 7, 1925

B. G. Jamieson: On the system of the Edison Company in Chicago, there has been built up within the last four years, a 33,000-volt nominal voltage, 60-cycle system of about 360,000 kilowatts. The transformers were generally equipped with the tap changing system described, the earlier forms with the double winding, and in other cases, a system which involves the step switching scheme with a connected reactor giving the same effect that the last author described.

The operations have been about forty in number, and from the standpoint of the effect on the load, nothing more could have been desired. Changes were made promptly, and we found that with approximately two and a half per cent steps, we got all desired smoothness. It came to our notice, however, very early in the development of these schemes that the complication added to the transformers indicated the desirability of getting the maximum amount of this extra system outside the tank. We are not yet able to take a final position in the matter of requiring this development further than to call to the attention of engineers the many extraordinary things that happen in transformers and the undesirability of having minor troubles or difficulties augmented by the proximity or presence of supplementary internal devices of this character.

As to the schemes of regulation involving the regulator system, this refinement will, I believe, be necessary only in exceptional cases, but where we have used the double winding we are prepared to add the regulator when necessary.

In our committee work in the N. E. L. A., some discussion has arisen regarding the nomenclature, and I must say that there was not complete agreement on this score. The name tap changer and the name *ratio adjustor* were offered for consideration, but the choice seems to be still open. Generally speaking, one associates with the term tap changer a minor piece of equipment and with the term *ratio adjustor* a somewhat more comprehensive system. It would appear from what has been seen that perhaps the term *ratio adjustor* has a little more exact significance.

H. W. Smith: These papers point out the need for some scheme of regulating transformer voltages under load, and mention one solution. I wish to point out, however, that other schemes have been used, and in considering any given problem, these alternatives should be investigated. A tap-changing scheme has been used in which the taps have been brought out of the transformer and changed by oil circuit breakers using an auto transformer in switching from tap to tap. This also provides a method by which additional voltage points can be obtained half-way between the taps so that, for instance, with five taps, nine voltage steps can be obtained. Four 15,000-kv-a., three-phase transformers using this scheme are in operation in Chicago. This scheme has also been used in connection with air-blast transformers supplying converters. The transformers having a primary voltage of 11,000 and standard contactors were used for changing the taps. This equipment has been in use in San Francisco for several years with satisfactory operation.

Another scheme which is particularly applicable to an interconnection between high-voltage systems, is that of using a combination of transformer with an induction regulator to bridge between the taps of the transformer. This equipment is termed a "step induction regulator." An interesting equipment involving this scheme and rated at 15,000 kv-a. has been used to interconnect the Tacoma Municipal System with the Seattle Municipal System. The Tacoma voltage is 50,000, three-phase, delta-connected, while the Seattle voltage is 57,000 volts, three-phase, star-connected. With the equipment, a voltage variation of 48,000 to 64,000 on the star side is provided. This installation has been described in an article "The Tacoma-Seattle Power Exchange Line," by R. E. Towne in the *Electric Journal* of June 1923. This same scheme has been applied to synchronous converters to get a large range in voltage for re-energizing a d-c. Edison system when a shut-down occurs.

Another scheme which has been used is that of opening the delta on a bank of transformers, switching the taps on one transformer, then replacing it and doing the same with the remaining transformers. This has been applied to a bank of transformers supplying synchronous converters for obtaining low voltages to re-energize a dead Edison system.

There will be a large field for tap changing on transmission systems supplying scattered areas where the tap-changing equipment must be relatively inexpensive. An experimental installation is being supplied to one property which will use air-break switches with the ordinary type of tap changer. The operator will disconnect one transformer by means of air-break switches, operate the tap changer, close the disconnect switches again, and then carry on this same procedure in the case of the remaining two transformers. The scheme, of course, relies upon the operator to perform the functions in the correct rotation.

A. H. Kehoe: It is important from the operating standpoint that this equipment, which becomes a controlling element in our large capacity lines, should be specified and manufactured in a manner to make it reliable without constant inspection. On the other hand, all operators of such equipment should have regular inspections made until simplified designs have been developed which demonstrate in practise that such inspections are not required.

H. R. Wilson: I believe that we are indebted to C. R. Oliver for inaugurating the idea of changing transformer taps under load by using the scheme of parallel windings. About ten years ago, he installed at Pawtucket, two 18,625-kv-a. three-phase transformers operating in parallel. Each transformer was provided with *ratio adjustors*, and high and low tension oil circuit breakers. Tap changes were accomplished by opening the breakers of one bank, changing taps by means of the adjusters, and closing the breakers and the operation being repeated on the second bank.

As regards using disconnecting switches, The Consumers Power Company has had in operation for several years, a scheme whereby switches connected the taps in each leg of the delta so that the taps could be changed in one leg at a time; the transformer operating in open delta during the period the taps were being changed.

1. A. I. E. E. Journal, Vol. XLIV, July, p. 752.

COOPERATIVE COURSE IN ELECTRICAL ENGINEERING OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY[1]

(TIMBIE)

SWAMPSCOTT, MASS., MAY 8, 1925

H. B. Smith: It has been recognized for years by educators and managers responsible for engineering and industrial organizations that the closer the contact obtainable between the industry, the engineering organizations, and the colleges, the better for the product of the college going into engineering work.

That has long been acknowledged a mutual advantage, and various attempts have been made in different ways to meet that recognized condition. The plan presented in this paper is one of the prominent efforts along this line, and it is deserving of the greatest success and support.

We have been trying a modification of this scheme at the Worcester Polytechnic Institute. It comes down, like many other problems of the electrical engineer, to a question of frequency. We have, applicable for the trade-school training I think, a rather high frequency as a possibility. It has been tried out in the Cincinnati scheme.

For an engineering training, it appears to me that a somewhat lower frequency is necessary, because of the necessity of delving more deeply into the more advanced theoretical questions, which takes a longer period of absorption in the average brain. The period selected by Massachusetts Institute is, I think, a recognition of that necessity.

At Worcester, about six years ago, we attempted the plan of sending our students out at the end of their junior course into engineering organizations for fifteen months before the senior year, so that before receiving their senior theoretical training, they get a very thorough contact with engineering organizations and appreciate what problems have to be met after graduation.

There is no better place for the young man to receive his purely technical theoretical training than the college. I believe the engineering organizations and the industry generally recognize this. On the other hand, it does seem to me that there is no better place than the engineering organizations to get the practical contact and the most up-to-date practise. I think that those two features are acknowledged by everyone.

I hesitated about sending our men out for fifteen-months' periods, (fearing the difficulty that they might have in coming back to their theoretical training following so long a period), until after we had the experience of men who had been out during the war period for two or three years, sometimes under far more distracting conditions—conditions that would take them away from the thought of their theoretical technical training; and we found that those men who came back to us were able to get their technical theoretical work with a "lost motion" of not more than two weeks on the average.

These experiences encouraged me to try this plan of fifteen months, because fifteen months is a period which many of the organizations have thought desirable as training courses for their men taken from colleges after graduation; also because the fifteen months would fit between a junior and a senior year without in any way disrupting the college courses. We tried it.

Every man we have had on that plan for the last six years, with but one exception, has come back to finish the senior work.

We have been able to secure the cooperation of the engineering organizations that we have approached on the question. Thus, if a man knows at the end of his junior year what he is heading for five or ten years hence, (a great many men don't know even on graduation or after graduation, but some do know, or think they know), it is possible to arrange experience for him heading in that direction.

Thus far, our experience with that method has been entirely satisfactory. It is a question of frequency, and, like a question of frequency in other relations, is open to debate.

At the present time about fifty men have been on that plan. We expect that a small percentage of the total number of juniors will go on the plan, because many men, for family or financial reasons, feel that they must go through to graduation as early as possible. It makes really a five-years course for the man, four years in theoretical technical training; fifteen months in actual experience as a unit in an engineering organization.

Their earnings vary, probably averaging in the neighborhood of \$100 to \$120, occasionally more than that, per month. The men are able to come back to their senior year with considerable saving—some of them do and some do not.

W. L. Smith: Northeastern University started its work in 1912, opening the cooperative engineering plan with eight students on a four-years basis, and the original idea of alternating their cooperative work for two-weeks periods. At the present time, we have in the engineering school 1104 students, and we are alternating on a five-weeks period.

We do not aim to do exactly the same type of work as the Massachusetts Institute of Technology; we are trying to give to the men who are graduates of Class-A high schools, and who must, if they are to get a technical training at all, be earning during the whole time, an opportunity to get a good, thorough technical foundation. We have found that where we take the men for their four-years course, after considering quite a number of different alternating periods, the five-weeks period works out fairly well with the work that we are trying to do.

We have, at the present time, about 100 firms cooperating, taking electrical engineering students, and we send them practically all through New England and into New York State. They find no difficulty in alternating there. Some of the employing firms would like a little longer period; others think that it is extremely satisfactory as it is.

We have minimum rates of pay which we establish—so much for sophomores, so much for seniors, so much for juniors—and some of the concerns pay much higher than the minimum. For instance, students going into one particular cooperating firm would not be taken under \$30 a week, simply because the company's working arrangement with its regular employees makes it necessary to pay that amount to the students.

J. C. Clendenin: The student engineering training courses conducted by the General Electric Company have two principal objects; first, to provide a group of men competent to test electrical and mechanical apparatus; second, to provide a source from which there may be obtained men qualified to fill engineering, sales and other positions where technical training is needed.

This student engineering training course was started at the Lynn works about forty years ago, at which time it was called the "Expert Course." From this simple beginning, coincident with the development of the electrical industry and the manufacture of larger and more varied apparatus, the courses have been extended to give a broad general training in practically all of the electrical and mechanical apparatus which is being used in the distribution of electrical power. The Massachusetts Institute of Technology cooperative course, which is now operating so successfully as a part of our student training program, was organized in 1917.

Since the cooperative feature of this course begins at the conclusion of the sophomore year, the men may be selected for this cooperative work with some knowledge of their adaptability and fitness. The work of selecting these men is mutually shared by representatives of the General Electric Company and of the Massachusetts Institute of Technology.

Since these men alternate, three months at the General Electric works and three months at the Institute, during the remaining three years of the course opportunity is afforded not only to study their capabilities but also to guide them in the lines for

1. A. I. E. E. JOURNAL, June, 1925, p. 613.

which they show the greatest aptitude, with the result that when this course is completed not only are the representatives of the General Electric Company in a position to offer employment to such men of this group as are best qualified for any particular work, but the young man who has taken the training is able to form some definite conclusion regarding the character of the work which he wishes to undertake, whether with the General Electric Company or some other organization. Past experience indicates that approximately 50 per cent of the men from this course are retained by the General Electric Company.

The success of this course is in a large measure due to the splendid spirit of cooperation which has been shown by those of the Institute who are responsible for directing the course and the students, who have, without exception, complied with the regulations of our organization, by their enthusiastic manner making the task of providing them with suitable work a most interesting one.

I believe I reflect the spirit of those other persons in the General Electric Company who are associated with the student-training work when I say that our interest in these men employed on our training courses is just as great in helping them to get successfully started in their chosen line of work as in providing men for our own staff.

We enter into the work of student training with the feeling that by a helpful and sympathetic interest in these young men who are just starting out on their life's work, we can be of help to them in shaping a successful career whether they remain with the General Electric Company or take up work with some other organization.

C. A. Adams: Whenever I hear a discussion of education which deals largely with the subject matter or curriculum, whether with or without the industrial-cooperation feature, I have a feeling of the futility of it all, because these discussions as a rule miss the vital point of the very meaning of the word "education." Our present methods fail almost entirely in teaching the young men to think for themselves. They are taught to accept what they are told or what they read. They are taught conventional and approximate methods of solving conventional problems without knowing what the approximations are and without thoroughly understanding the basis of the method. They are not taught to acquire a thorough grasp of the fundamental principles, to make the subject their own, and to develop their own solutions. When the range of work with which they are concerned gets outside of the range for which the approximate methods were adapted, they are helpless.

We specialize too much. A man who has the fundamentals of engineering can take up any branch and acquire the necessary information and technique of that branch in a surprisingly short time, if he has been trained to think for himself.

In any scheme of education, whether with or without the cooperative feature, the chief factor is the teacher. The trouble is that most of our teachers are trained in the same superficial methods and do not themselves have a thorough understanding of the subject.

Until our young men get to the point where they first demand sound evidence of the facts underlying their problem and acquire the habit of reasoning carefully and sure-footedly from these facts with the aid of the fundamental principles involved, making their own approximations where they find them to be permissible for the particular problem in hand—until they get to this point they are not educated.

A. J. Krupy: As a student of the cooperative course of M. I. T., I should like to express my belief that the course offers exceptional opportunity for practical experience along the line of modern engineering practise.

Having a background of European education which, in general, is of a decidedly theoretical nature, I chose this course to secure practical experience combined with advanced engineering subjects, which I do not regret. I feel it helped me a great deal to acquire a good grasp of the problems before the engineering beginner and that the course itself is a decided success.

P. H. Rutherford: I should like to say a word as a graduate of the first class of the cooperative course. The greatest advantage, I think, that the student gains from taking the course is that he obtains a point of contact not only with industry but with the men in the shop. He appreciates the reasons why the men in the shop are sometimes antagonistic to the management, and he knows when he is in the office, after his graduation, the things with which he has to contend.

Another great benefit is the experience obtained in the shops. Many times when we are designing parts for new apparatus it is a great help to know whether a certain casting can be made, and the experience that one obtains in the foundry is a great help in designing these various parts.

After a student has finished and goes with the company with whom he has been doing the cooperating work, he feels more at home than if he had just come in from the outside and obtained employment with that company. He really feels that he belongs there, and can start in his work rather as an old employe.

V. Bush: The enthusiasm of a young man of twenty-one is the most powerful force we have in the world. If a man is enthusiastic about his studies, you can't help teaching him. He will learn. If he is enthusiastic about his work, he will get ahead. If, on the other hand, he is disgusted with either, the depths of despair of a young man of twenty-one are equalled only by his enthusiasm on the other side of affairs.

So far our experience with this course has been that the men, from their contact with the work, become enthusiastic, more enthusiastic than the normal man, in regard to their theoretical studies, and that on account of their contact with theoretical aspects, they enter the factory with enthusiasm for the work and to ambition coordinate the two.

E. S. Mansfield: We feel that a great deal has been done through this cooperative course. It benefits not only the college, but I think it benefits the company more. When we first started in with this cooperative work at the Edison Company in Boston, we found many heads of groups who didn't like the student idea. But that has all been changed. We feel that they gladly welcome these students into the work; they are glad to help them all they can, and they feel that they are getting more out of the students than the students are getting out of them.

There is one important thing that Professor Timbie will realize,—we are very critical about the kind of people we get into that course, because if a man isn't of the type naturally, and fundamentally of the right character, he isn't the type of man we want.

M. W. Alexander (communicated after adjournment): Two features of the cooperative course operating between Massachusetts Institute of Technology and the General Electric Company, which Professor Timbie described, might with profit be adopted by any educational institution. In the cooperative course the student works forty-eight weeks per year as contrasted with from thirty to thirty-six weeks in the more usual college course. The reduction of vacation periods to a total of four weeks per year in the ordinary college course would, with certain other rearrangements, permit of completing the course in three years. The year saved, if put into useful employment, would go a long way toward covering that necessary period for acquiring practical experience, knowledge of detail and atmosphere that is essential before a college graduate can fairly integrate himself into industry and begin to make any really valuable practical application of his higher education. If the year saved should be put into further study, his education in the basic sciences of engineering could be much more thorough and some of the desirable broadening general subjects be in-

cluded or amplified. Even though college vacation periods are used by many students in useful employment, probably more often, with the primary purpose of earning expense money rather than gaining practical knowledge, it seems reasonable to believe that there is much vacation time wasted that would best be put into either shortening the college course or making it more thorough and comprehensive.

The other feature of the cooperative course that might well be adopted by any college is that of the pedagogical principle that underlies cooperative plans; that is fixing currently in the student's mind the purpose and application of much of the college instruction by concrete illustration and practical trial, thus giving him a true perspective for his theoretical and scientific work. Although there are many important elements of a thorough engineering training to be obtained only in practical employment, such as those resulting from the human contacts with workmen and from encountering those difficulties that hedge about many applications of theory, there is nevertheless a lesson for those who do not adopt such a scheme in the cooperative plan of instruction such as described in this paper. A brief examination of students in many of the regular courses of college instruction will show that they do not have a clear idea of the practical application of their instruction or its relation to other subjects involved in their education. This is a condition that in many cases may be remedied by more thoughtful and intensive teaching and by the use of illustrative methods that are available without going outside the college walls.

W. H. Timbie: In connection with the remarks of Prof. H. B. Smith I should like to point out that the difference between the M. I. T. cooperative course and the usual cooperative course is much more fundamental than a matter of frequency of alternation between study and work. It is more a question of the selection and organization of the material constituting the practical experience.

At M. I. T., we are not so much concerned as to just when the student shall get his engineering practise or in just what size installments, although we believe that the time and size of these installments as arranged in the M. I. T. course have decided advantages. Our chief concern is properly to select and organize this engineering experience so that it shall constitute a clean-cut course in practical experience just as our various subjects in science and mathematics constitute a clean-cut course in electrical engineering. We are simply applying the same pedagogical principles to the attainment of the proper engineering practise that we apply to the presentation of the electrical engineering studies at the Institute. In both cases it is not a matter of length of term but of selection, organization, and administration of the material.

In reply to Prof. Adams' remarks, we can only state that we believe that the engineering practise consists of certain fundamentals just as the engineering science consists of certain fundamentals. In the cooperative course we are making a conscientious effort to see that the students get these fundamentals of engineering practise as well as the fundamentals of science. The ordinary electrical course leaves it more or less to chance as to whether the student receives proper experience. We believe that the fundamentals are necessary. We, accordingly, offer courses in which we believe the students will best obtain the fundamentals.

RECENT IMPROVEMENTS IN A-C. INDICATING INSTRUMENTS[1]

(Hoare)

Swampscott, Mass., May 9, 1925.

C. G. Brown: As a-c. ammeters were previously made, the d-c. readings were so different according to the direction of flow of current that it was not feasible to calibrate on d-c. The metal in the moving system of the a-c. ammeter which Mr. Hoare has described has its direct and reversed d-c. readings so nearly alike that when necessary it can be checked on d-c.

B. W. St. Clair: One of the very important points of instrument construction mentioned in Mr. Hoare's paper that has a great deal to do with the dependability of instruments in service is that of instrument springs. The forces involved in indicating instruments are surprisingly small. The usual full-scale torque range is from 0.1 millimeter-gram to 10 millimeter-grams, which translated into more usual terms corresponds to 6×10^{-5} to 6×10^{-7} ft-lb. Despite the smallness of the forces involved, the spring does a remarkable piece of work, as in the better grade of test instruments the error of its indication is generally less than 0.1 of one small division, which is approximately one part in a thousand. Translated into other terms, the ordinary instrument spring on the better-grade instruments is dependable to about one minute of arc. Dependability of this high order is secured only by very careful choice of materials, unusual manufacturing facilities and by great care in the mounting of the spring in its final supports in the instrument.

I mention the springs as one of a number of very highly important members that contribute to the final dependability of the instrument. The magnets, the bearings, the constancy of shape of the windings, and many other factors are of equal importance.

THE MEASUREMENT OF ELECTRICAL OUTPUT OF LARGE A-C. TURBO GENERATORS DURING WATER-RATE TESTS[1]

(Lee)

Swampscott, Mass., May 9, 1925

H. W. Oetinger: Reference is made to the checking of instrument transformers with equivalent secondary burdens. The usual procedure in determining this secondary burden is to calculate it from the published data of the instrument coil constants and the size and length of leads. Where test wiring is used exclusively, there can be no question regarding this procedure but where the test instruments are inserted in conjunction with station instruments and wiring, there is some question as to what is actually in the circuit. In one case it was found that coils of unknown and variable volt-ampere characteristics were left in circuit. In such cases it seems desirable to actually measure the secondary burden and include all connections and instruments to be used during the test. A voltmeter, ammeter and wattmeter can be used in conjunction with a load box. The disconnection is made at the terminals of the instrument transformers and voltage applied to the leads at this point.

Under "Observations" mention is made of readings covering a wide range of load variations. For such load conditions it is important that the wattmeters used have practically no scale errors within the range of possible load swings. If the generator output is calculated strictly in accordance with the statements under "Calculations" this would not be necessary, but the usual procedure is to correct the average wattmeter reading only and not to average the corrected readings. The latter involves an immense amount of additional labor which can be eliminated by observing the above requirement.

With reference to "Photographic Observations," these have the distinct advantage of giving a permanent record of the instrument indications and any questionable data can be checked very readily by reading the film. There is, however, one point which should be recognized if speedy determination of the kilowatt output is required. By the visual method, final results of the test can be calculated within two hours. By the photographic method it is necessary to develop, dry and read the film which involves several times the delay required by the visual method.

J. A. Johnson: In the old days, when water was measured

1. A. I. E. E. Journal, Vol. XLIV, September 1925, p 969.

1. A. I. E. E. Journal, Vol. XLIV, August, 1925, p. 847.

by means of weirs and piezometers we never had to worry much about the accuracy of our electrical measurements because the hydraulic measurements were so much worse. But within the last few years, there have been new methods perfected for measuring the water supplied to a turbine, so that we are now able to get hydraulic measurements so accurate that they have put the electrical engineer on his toes to produce electrical measurements of equal accuracy. We found that the discrepancies we were getting in our over-all results were apparently due to inaccuracies in the electrical measurements rather than the hydraulic. So I welcome Mr. Lee's paper showing that electrical measurements can be taken accurately by observers with indicating instruments, and that it is not necessary to use photographic methods, because it is always much easier to use apparatus which is available in any standard power company's laboratory than to have to develop special apparatus.

W. H. Pratt: Mr. Lee's paper shows what can be done by using instruments in a careful way, and it recalls to me work that I did about twenty-five years ago when we first had occasion to calibrate large watthour meters on very fluctuating railway loads. We found by averaging results on readings, simply taken as Mr. Lee describes, not attempting to average in the mind but putting down the readings as seen from moment to moment, that it was perfectly possible to get successive calibrations in agreement within a matter of a few tenths of a per cent, frequently within two-tenths of a per cent. So I think there is no doubt that this averaging of a moderate number of observations is an absolutely valid method.

In Mr. Lee's paper the use of a portable test meter is mentioned, and I think as a matter of record we should note that this is a use for which this meter was not originally intended. The accuracy that he seeks to obtain is higher than would be requisite when the meter is used as it is intended to be used. The meter in its proper field fully meets the conditions required.

F. V. Magalhaes: It is comforting, as well as interesting, to those handling tests involving the ordinary instruments and observations, to have the accepted methods of handling tests proved reliable by Mr. Lee's presentation of the use of the camera to check the readings of the instruments.

I should like to use Mr. Lee's paper as a vehicle for advancing a plea; and in advancing it, it is not intended as a criticism of this particular paper. The plea is for a careful consideration and statement of the necessities involved in any problem of measurement. These necessities or specifications, as well as the limitations of the instruments that may be selected for the test, should be clearly understood in the minds of those conducting the test.

The use of the rotating test meter for various purposes and its limitations have been quite actively under discussion during the past year or so and it is the use of this particular instrument that I wish to discuss. The uses which have been proposed or suggested for this instrument can be classified roughly into four necessities. The instrument was specifically designed to meet one of them but an effort is being made to use it for the other three. This effort has been attended with some lack of success and irritation on the part of those attempting it.

Firstly, there has been for many years a necessity for a convenient portable instrument for use in the field for making several hundred or several thousand tests a month of the house-type watthour meter installed on the lines of public utilities. For that purpose, experiments were started possibly twenty or twenty-five years ago, toward the development of a portable test meter or rotating test meter. The conditions to be met were primarily portability with a combination of as many ranges or scales within one instrument as it was possible to develop. The accuracies aimed at were, let us say, within 0.75 per cent.

Many are familiar with the successful use of the portable test meter in connection with the routine tests of service-type watthour meters in customers' premises.

The second problem is the one to which Mr. Lee's paper refers; namely, the measurement of energy during water-rate tests or acceptance tests on generators.

On tests of this character, the requirements for accuracy are more rigorous than for the field tests of commercial watthour meters and could probably be called $\pm$ 0.25 per cent rather than $\pm$0.75 per cent which was set up in case No. 1. Tests of this character would be made indoors in a station and it is at once apparent that the requirements for this test are different from the requirements which dictated the development of the rotating test meter for use in the field. There is no real necessity for using an instrument primarily designed for portability. Also the precision expected is much greater than that for which the portable instrument was originally designed.

The third problem that has arisen recently is the necessity for a reference standard to calibrate the watthour meters used for the interchange of power between large systems. These watthour meters are, as a general rule, very few in number and are always located within a power house. There would again be no necessity for the use of an instrument specially designed for portable use and an effort made to attain a precision of possibly $\pm$ 0.25 per cent.

A second variation of this same problem is the necessity for an instrument to calibrate the meters which sell energy directly to a small number of large customers, such as some of the utilities in the Niagara territory which have a total of possibly one or two hundred watthour meters, representing all of their customers as compared with other utilities having several thousand or several hundred thousand watthour meters. The instrument used to calibrate these relatively few watthour meters could properly be of different characteristics, possibly not quite so portable but providing a higher precision in the measurements. In this case a precision of possibly $\pm$ 0.20 per cent or 0.30 per cent might be required which again is much greater than the 0.75 per cent which the accepted type of rotating test meter now provides.

The fourth problem is the necessity for a reference standard of some description in the laboratories of public utilities or universities or public-service commissions as an instrument to certify the accuracy of the rotating test meters that are used in the field. Here again the conditions under which the instrument would be used are laboratory conditions so that there is no necessity for an instrument primarily designed for portable use and the requirements for the precision of the measurements would be of the order of $\pm$ 0.20 per cent.

To sum it up, the present type of rotating test meter which is being used successfully by the utilities for making routine field tests of watthour meters very possibly will not meet the requirements of other forms of tests which I have just outlined. It is possible, however, that a different form of test meter may be developed which will meet all of these conditions satisfactorily.

To present an illustration from another field of measurement, I will refer to the subject of time measurements. The stop-watch was developed a great many years ago, primarily for the purpose of being carried around in a person's pocket to time races. Since this original development and use of the stop-watch, there have arisen the necessities of the electrical business with their incidental electrical and time measurements. An effort has been made to use this stop-watch in connection with more or less precise electrical measurements. The stop watch has continuously suffered from the comparison of the results which it can supply with the results obtained from good grade electrical instruments. If, precise measurements of time are required in the laboratory, it is quite obvious that some different form of measuring device should be used and this would undoubtedly be a device not primarily designed for portable use in a person's pocket.

The accuracy of the results which can be obtained from the stop-watch is probably adequate for timing a horse race or boat

race, but no one should presume to use a stop-watch for the measurement of the time of flight of projectiles or the discharge of a condenser or other problems which have arisen since the stop-watch was originally designed. I am loath to class the rotating test meter with the stop-watch, but the comparison is only made to illustrate the difficulties which are being experienced with the use of the rotating test meter. These difficulties arise not with the instrument itself but from the use to which it has been applied.

C. G. Brown: There is one point to which I should like to call attention—probably a great many of Mr. Lee's readings are taken when the needle of the instrument is remaining fairly stationary. I think that if he were to have a large number of readings taken in every case when the needle is moving rapidly, (we shall say, up scale), he would find considerable difference in the observations from the different men. Some men would consistently read lower, while some would consistently read higher. It would also be interesting if, in an ordinary series of tests, those values that are taken when the needle is swinging rapidly up at the time of the observation could be marked, and then see how those results check up with the values obtained when the needle is swinging rapidly down.

B. W. St. Clair: Mr. Lee's suggestion that in making very important tests the previous history of the instruments involved should be investigated before putting undue dependence upon test results is a very good one. The demands made upon test equipment for constancy under unusual service conditions are very severe in the kind of tests referred to in Mr. Lee's paper. It is seldom in ordinary testing work that conditions as severe as these will be encountered. When consideration is given to the many factors that enter into instrument constancy it is really surprising that test equipment performs as well as it does under the adverse conditions often met with in turbine-room tests.

M. W. Leonard and E. J. Mommo (by letter): If any water-rate test is conducted throughout with the same care and attention to detail which Mr. Lee advocates for the electrical part of the work there should be no difficulty in obtaining a final accuracy of $\pm$ 0.25 per cent.

As the steam measurements are generally the greatest source of error, including not only these of initial pressure and superheat, but particularly that of weighed condensate, we should like to ask Mr. Lee if he considers the three-wattmeter method as most suitable for water-rate tests in general? Even where tell-tales are installed between double valves, and water lines are protected by blanks, there are still possibilities of error in calibrating weighing scales, measurement of gland leakage, condenser leakage, condensate from steam-jet pumps, etc.

The three-wattmeter method of measuring electrical energy is undoubtedly simpler than the two-wattmeter method so far as the application of the meter corrections is concerned. From a practical standpoint, however, we wish to point out that there are certain disadvantages to be encountered with either of these methods where indicating instruments are used. Under Mr. Lee's method three observers, one relief observer, and a computer are necessary. This means not only a multiplicity of instruments and high-test costs, but delay in computing and checking the increased amount of data. The eye strain on the observers, while not serious on a test of short duration, might well be a factor to be reckoned with on tests made every day for a week or so.

The polyphase-integrating-wattmeter method offers none of the above difficulties. Most of these instruments have a very constant calibration and involve very little difficulty in checking to within $\pm$ 0.1 per cent with a rotating master standard with 100 per cent power factor on each element. When equipped with a high-speed dial register ample precision can be obtained on tests of two-hour duration, readings of the dial being made at half-hour intervals. There is some question as to the advisability of running tests with a duration of less than two hours, not so much due to the precision of the integrating polyphase wattmeter but because of water levels, variations in condenser vacuum, and temperature changes in generator windings.

With the addition of a properly applied set of instrument-transformer calibrations it would appear that any further degree of refinement involving phase-angle corrections, etc., would be unnecessary with a single polyphase wattmeter because of the probably greater errors in the steam measurements. An over-all electrical accuracy of $\pm$ 0.25 per cent, including instrument transformers, may be reasonably expected even with the two elements of the polyphase meter checked at 100 per cent power factor. If greater accuracy is desired the wattmeter elements may be checked separately at 100 per cent and 50 per cent power factor, corresponding approximately to the electrical condition existing in the meter with generator loads at 85 per cent power factor, a value usually obtainable.

E. T. Brandon (by letter): I think that the refinements of measurement used would be justified only where a very large number of tests of first importance were to be made. Some of the corrections said to be accomplished are usually so very small that they are negligible no doubt in comparison with the error of observation of the meter reading itself. If the correction is made, I suppose it justifies itself by indicating that it has been accounted for, even if negligible.

The three-wattmeter method recommended has advantages, but would require temporary connection of potential transformers in some cases, and I think the advantage of having all wattmeters operating at high power factor is offset by the fact that three meters have to be read simultaneously, which is difficult. I think the trouble of having one wattmeter reading at low power factor, as is the case when the power factor of the load is much below 0.80 and the two-wattmeter method is used, could be overcome in most cases by an adjustment of power factor to unity before the test is started. We have been able to do this in our tests at all except light-load conditions for the generator under test.

No mention is made in the paper of the use of the polyphase wattmeter. This meter, in its portable form, usually has high accuracy and the additional advantage that it gives the total power on one meter, thus insuring the recording of a simultaneous reading. Adjustment of the load on the generator to approximately unity power factor would be necessary for the highest accuracy when the polyphase meter is used.

With reference to the electrical readings taken on the Gibson tests at Queenston, we have, in general, made corrections similar to those suggested and presumably used in the tests described in the paper. The Gibson test is different from the water-rate test in this respect, namely, that the power being delivered to the turbine is desired at the instant the gate starts to close. The quantity to be measured, therefore, is not the average power over a period of time, as in the case of the water-rate test. In correcting the meter reading obtained, we have taken account of the ratio and phase-angle errors of current and potential transformers, which have been previously calibrated, and the error in the meter itself. The wattmeter is always calibrated before and after test against our secondary standard, and is transported by messenger.

In noting that use was made of watthour meters, I might say that we have tried these, but were unable to get a very close check with the indicating wattmeter reading. This was due, no doubt, to the fact that the watthour meter would give the average kilowatts for the time immediately preceding the dropping of load, whereas the wattmeter gives the output at the instant of shut-down. The per cent error in the watthour meter is larger because the time during which it is reading is relatively short, not more than two minutes as a usual thing. In water-rate tests of an hour's duration, during which the load is held reasonably constant, this error would become very small.

I was interested to note the comparison between visual and photographic methods of obtaining the readings on the wattmeter. We have had this method in mind for some time, and expected that the extra cost of such a method would be justified by the increased accuracy obtainable. Apparently where the average of readings taken over a length of time is desired, competent visual observation can be depended on to give results as accurate as the results obtained with the camera. I still believe, however, that where an instantaneous reading is desired, greater accuracy would be obtained by photographing the position of the wattmeter needle.

E. S. Lee: With reference to using a polyphase integrating watthour meter as suggested by Messrs. Leonard and Mommo, the procedure, as described in the first part of the paper, regarding watthour meters should be followed. As regards the need for two-hour tests, the evidence submitted in the paper shows the sufficiency of tests of one-hour duration.

With particular reference to measurements of electrical power output from water-wheel units as mentioned by Mr. Brandon where the water flow is measured with the Gibson apparatus, conditions are quite different from turbine-generator testing in that the electrical power output is desired at a particular instant following a period of constant power output. The results of repeated tests will give the deviation. If the latter is too great, more refinements will have to be introduced into the measurement. Photographic observations would probably be of no advantage over the visual however, because of the steady conditions required preceding the observation which would allow the instruments to be read visually.

The use of a polyphase indicating wattmeter requires that the instrument be compared under the exact test conditions. The suggestion of adjusting the generator power factor to unity is not generally applicable as the generator must be tested at its rated power factor which is frequently less than unity.

Discussion at Annual Convention

SEPARATE LEAKAGE REACTANCE OF TRANSFORMER WINDINGS[1]

(Dahl)

TRANSFORMER HARMONICS AND THEIR DISTRIBUTION

(Dahl)

RESOLUTION OF TRANSFORMER REACTANCES INTO PRIMARY AND SECONDARY REACTANCES[2]

(Boyajian)

Saratoga Springs, N. Y., June 25, 1925

J. F. Peters: In Mr. Dahl's paper, as far as I can see, the assumption is made that the triple-frequency component of magnetizing current follows Ohms' law, that is, there is inherently in the transformer a triple-frequency voltage and the triple-frequency component of current that will flow is that voltage divided by a triple-frequency impedance. If this is the case, then by decreasing the triple-frequency impedance to a small value, the corresponding current could be made quite large. Obviously this cannot be the case because when the triple-frequency current reaches a certain value, which is approximately 40 to 45 per cent of the fundamental-frequency current, the voltage wave takes on a true sine shape in which case the triple-frequency voltage disappears. It may not be possible to decrease this impedance to a very small value within the transformer, but if it is a true impedance, it can be counteracted to any desired degree externally. Also, if no triple-frequency current is permitted to flow, there will be a large triple-frequency voltage appear across each of the phases. In a transformer of commercial proportions and flux density, this voltage would amount to approximately 75 per cent of the fundamental-frequency voltage, which, in the transformer analyzed by Dahl, would amount to 100 volts triple-frequency. Then the triple-frequency current that should flow in any winding should be that voltage divided by this triple frequency impedance. He finds in winding one a triple-frequency impedance of approximately one-half ohm. This should give a triple-frequency current in the order of 200 amperes. Actual measurements show approximately two amperes.

Since this triple-frequency impedance is not a true impedance, that is, its X value is not a consonant, there are a number of operations used by Mr. Dahl that may be questionable. For instance, in his paper on *Transformer Harmonics etc.*, on the seventh page, first column, paragraph 3, in measuring the triple-frequency current in two delta windings, when measuring the current in one winding, the corresponding resistance in the other winding was short-circuited in order to use the same measuring instrument in both, and vice versa. This resistance in the measuring instrument is quite large. It is of the order of the total impedance of the winding. That means, in shifting from one winding to another, the triple-frequency current distribution between the windings has been changed and since the triple-frequency impedance obtained, applies only to the particular flux density and triple-frequency current under which the test was made, there is a chance for considerable error being introduced.

There is another point in connection with the paper that makes me feel that perhaps something not permissible was done. Mr. Dahl determined the triple-frequency impedance of his transformer by two methods: In the two-winding methods, he determined X_3 between coils 1 and 3 and found the value to be 1.275. By means of the three-winding method, he determined X_3 between windings 2 and 3 and found it to be 1.336. The distance between coils 2 and 3 is three-quarters of an inch. The distance between coils 1 and 3 is approximately 0.95 in. That being the case, the reactance X_3 measured between coils 1 and 3 should be approximately 25 per cent higher than measured between coils 2 and 3. Actually, he finds it to be approximately 96 per cent. So that there is a considerable discrepancy between X_3 measured by the two methods of the order of 25 or 30 per cent. That could hardly be considered within engineering accuracy.

The methods used by Mr. Boyajian are so simple and direct that I feel the chances of error are very remote and you will note in his one set of tests that he gives the distribution of triple-frequency current between two delta windings, that distribution changes with flux density which also shows the fictitious triple-frequency impedance is not a true impedance but changes with conditions.

V. Karapetoff: Consider a two-winding transformer, with or without an iron core, and disregard saturation and core loss. Such a transformer can be first replaced by one of one-to-one ratio of turns, and then by an equivalent diagram shown in Fig. 1 of Mr. Boyajian's paper (with a pure reactance in the exciting branch). In this diagram, the values of the leakage reactances Z_1 and Z_2 are perfectly definite, namely $Z_1 = Z_1^1 - X_{12}$ and $Z_2 = Z_2^1 - X_{12}$, where Z_1^1 and Z_2^1 are the total impedances of the windings (leakage plus mutual flux) and X_{12} is the mutual reactance. Therefore, rather than to convey an impression that leakage reactances are fictions valid for one purpose and not valid for other purposes, would it not be better to say that in a two-winding transformer these reactances have a definite meaning in the equivalent diagram and must be interpreted in the

1. A. I. E. E. Journal, Vol. XLIV, July 1925, p. 735.
2. A. I. E. E. Journal, Vol. XLIV, August 1925, p. 842.

actual transformer with reference to this equivalent diagram.

In a transformer with more than two secondaries, the indefiniteness of the division of the leakage fluxes among the individual windings lies in the very nature of the phenomenon. Consider for example a "split" single-phase line, consisting of two lines on adjacent cross-arms. The inductance of such a line depends upon the fractions of the total load carried by the two loops, and is different for different divisions of the load.

R. G. McCurdy: It seems to me that Mr. Boyajian is in error in stating that the difficulties which have arisen in dividing leakage impedances between windings are due to any lack of definiteness of the problem. The generally acceptable definitions of the individual leakage reactances are given by equations **10b** and (**11b**) of his paper. In two-winding transformers, when the exciting current is ignored, a single leakage impedance equal to the sum of the two individual leakage impedances may be used in computing regulation under load and with three-winding transformers ignoring the exciting current leads to the set of equations (**1**) (**2**) and (**3**) of his paper which express individual impedances in terms of the total leakage impedances between pairs of windings. I think it leads to confusion, however, to call such individual impedances of three-winding transformers "individual leakage impedances."

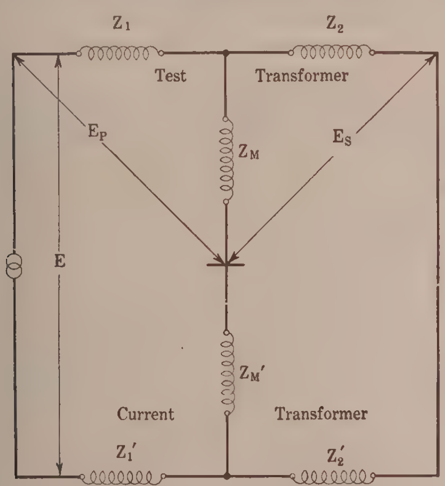


Fig. 1—Circuit Equivalent to Fig. 7 of Boyajian Paper with Current Transformer

When it is desired to determine division of exciting currents between different windings the above simplifying assumptions may not be made. Knowledge of the individual leakage reactances is then necessary. With two-winding transformers the simple equivalent network of Fig. 1 of Mr. Boyajian's paper may be used. This same network will also apply when considering the division of harmonic exciting currents in three-winding transformers when one of the windings is connected so that current of that frequency is suppressed. When current may flow in all three windings a more complicated network must be set up involving in general seven impedance elements.

While it is true that fairly simple arrangements may be used for determining the individual impedance of unity-ratio transformers, the application of such methods to transformers of other ratios presents difficulties. Take for example the circuit of Fig. 7B of Mr. Boyajian's paper. An equivalent circuit is shown in the appended Fig. 1. It will be evident by inspection that if the ratio of the secondary leakage impedance to the exciting impedance is the same for both the transformer under test and the current transformer, the secondary voltage will be zero and the primary voltage will be the same as that obtained on a short-circuit test. To determine the individual leakage impedances accurately by such a scheme the secondary leakage impedance of the current transformer would need to be very low and the exciting impedance very high as compared to the corresponding quantities of the transformer under test. Similar difficulties arise in the use of potential transformers in determining the division of exciting currents between the windings. Mr. Boyajian erroneously refers to the use of current transformers for this purpose.

For these reasons such methods for determining the individual leakage impedances do not seem to have much practical importance. Methods based upon the division of triple-harmonic exciting currents as discussed by Mr. Dahl appear to be more useful.

I note in comparing the test results of Mr. Boyajian and Mr. Dahl a considerable difference in the effect of magnetic density on the individual leakage impedances. I wonder if they have been equally careful to eliminate the impedances of measuring instruments and the effects of fundamental and harmonics other than the third. If I read Mr. Dahl's paper correctly he has largely eliminated errors due to these sources.

J. F. Peters: In view of what Mr. McCurdy stated I would like to amplify a point that I intended to make in the first discussion. I feel that the method that Mr. Dahl has used is of considerable value in many applications but it must be carried on with great care. The point I wanted to bring out was that the impedance obtained by this method applies only to that particular flux density and value of triple-frequency current, that it is not a true impedance. Care should be taken to retain the currents in their normal values. It is very unfortunate in the tests of the two deltas that Mr. Dahl made, that it was necessary to short circuit the resistance in one delta while measuring current in the second. This is more nearly a constant-current proposition than it is a constant-potential proposition. That is, if you were to insert in the corner of the delta sufficient impedance to reduce the current to one-half of the value, the residual triple-frequency voltage would be more than double. It will not follow that law at all and I feel that there may be some considerable errors in the actual values obtained by means of changing the distribution of current.

L. P. Ferris: Without entering into the technical controversy that appears between the papers by Messrs. Dahl and Boyajian, I wish to point out one example of the practical importance of a solution of this problem of the division of impedances between transformer windings. The example to which I have reference arises in connection with the inductive relations between power circuits and neighboring telephone circuits. When the neutrals of transformers are grounded it is important to know how the triple-harmonic exciting currents divide between the several windings of the transformer and particularly how these currents divide between closed deltas and the windings which are connected to the lines with grounded neutrals. This is a practical problem of great interest in addition to the problems of the effect of these impedances on regulation and on the division of load between windings.

It will be appreciated that this distribution of the triple-harmonic currents is a perfectly definite thing which is determined in practise as soon as the transformer is connected to the line and is controlled by the characteristics of the transformer and of the line. The transformer impedances involved may be called by the term "leakage impedance" or by some other term. However, there is this very definite distribution which takes place and it is necessary to carry our analysis to the point where this distribution may be predetermined. Thus it may be possible to predetermine the effect of a given change in connections or the effect of the addition of a new bank of transformers in a complicated network.

This problem was encountered by Mr. McCurdy, Mr. Cone and myself about ten years ago in connection with our work in

California with the Joint Committee on Inductive Interference. There are discussions of it in several of the technical reports of that committee which have been published by the California Railroad Commission.

The interest which is now being manifested in this subject by the colleges and several manufacturing concerns is very gratifying and I hope that it will continue until a common understanding is reached. This problem is one which is now engaging the attention of the Joint Subcommittee on Development and Research of the National Electric Light Association and the Bell System and I am sure that this committee will welcome any contributions to a solution by engineers either from the manufacturers or from the colleges.

C. T. Weller: I would like to discuss the subject of transformer reactance with particular reference to instrument transformers.

The use of instrument transformers has been referred to by Mr. Boyajian, so I will first comment on that. He states, under "Experimental Resolution," that when instrument transformers are used, the results will be complicated on account of the errors of ratio and phase angle introduced thereby. The ratio and phase-angle errors of properly designed instrument transformers are very small and can be very accurately determined if the condition of use can be reproduced in the calibration. If I understand the diagrams correctly, the condition described in Paragraph 1 can be accurately reproduced, but this is not the case with respect to Paragraphs 2 and 3, because it is entirely possible that the excitation of the instrument transformer may be wholly or partly supplied from the secondary due to differences in the characteristics of the transformers. I believe that the reference in Paragraph 2 should be to a potential rather than to a current transformer. In this connection, I would like to emphasize the point, which has already been made, that the detectors used in these tests may considerably complicate the results.

Instrument transformers are usually two-winding transformers with the primary surrounding the secondary. We have determined the approximate individual leakage reactance of the windings of a few of our standard transformers by calculation from the ratio and phase-angle and exciting-current results. The results are somewhat indeterminate due to the very small errors of the transformers. I might add here that in transformers of this grade, the effect of third and higher harmonics are negligible.

For potential transformers of moderate voltages, the primary leakage reactance may be taken to be about one-half of the total reactance obtained from the short-circuit impedance test. The range of phase angle, for the limiting cases of first assuming that the primary has zero leakage reactance, and second, that all the leakage reactance is concentrated in the primary, may not exceed five minutes. This indicates that the phase-angle error is very small. The leakage reactance appears to be constant under all normal load conditions. The total impedance and reactance appear to be the same at rated voltage as at the low voltage obtained in the impedance test. This makes it possible to determine in advance rather than to obtain by trial the power factor of the output which will give the maximum ratio error.

For current transformers of the ring-core type, with evenly distributed windings, the secondary leakage reactance may be taken to be zero. For current transformers of moderate voltage ratings and of low ratios of the square-core type, the leakage reactance may be taken to be approximately one-quarter of the total leakage reactance obtained from the short-circuit impedance test. This value applies over the range of rated current. For moderate overloads, the value may reach over one-half of the total leakage reactance. At heavy overloads, the saturation of the core greatly complicates the results.

To sum up, the approximate division of the leakage reactance of the windings of instrument transformers has been given for a few cases. These results were obtained by calculation from the ratio and phase-angle and exciting-current results and were referred to the results of the short-circuit impedance tests. This method is applicable to any two-winding transformers.

K. K. Palueff: In regard to the Resolution of Reactances, it is perhaps of interest to see the results of theoretical analysis of an elementary transformer which is—two concentric circles in air (one of which serves as primary and the other as secondary.)

These results can best be presented in graphic form.

Fig. 2 herewith gives voltage induced in exploring coils of various diameters placed concentrically with the circles and in the

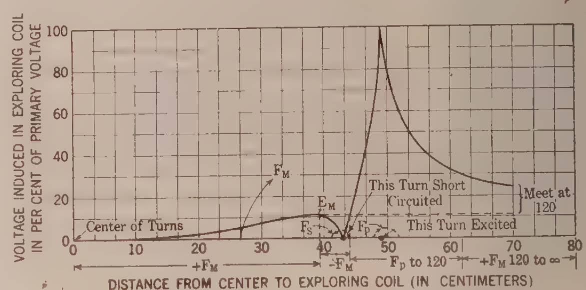


FIG. 2

same plane. This voltage is expressed in per cent of total voltage induced in primary (which in this case is the outer circle).

Fig. 3 gives voltage distribution in case the inside circle is primary.

In both cases the secondary circle is short circuited and is assumed to be of zero resistance. These examples are calculated for circles of 43 and 49 centimeter radius and round conductors of one centimeter diameter.

From the curves the direction and density of the flux in the plane of the circles can be determined.

In Fig. 2 we find that beginning from the center the voltage increases to a certain point (E_m) inside of the region enclosed by the secondary circle, and then gradually diminishes reaching zero in the region occupied by the shorter circle. This means that in the region encircled by the secondary there are two fluxes ($+ F_m$, $- F_m$) equal and opposite and with boundary line coinciding with the point of maximum voltage of this region, (E_m).

As we proceed the short-circuited circle toward the

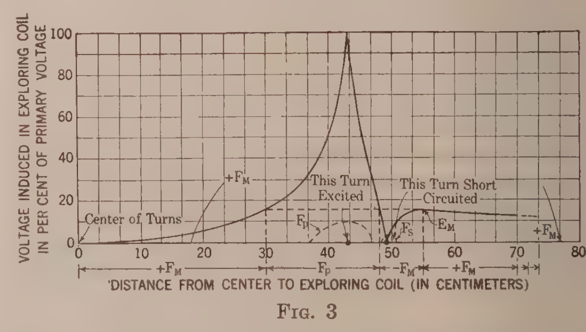


FIG. 3

excited outer circle voltage is steadily increasing. At a certain point it reaches the value of maximum of the region encircled by a secondary (E_m). This point therefore lies on the outer boundary of the secondary flux ($- F_m$).

After passing the primary turns voltage begins to diminish and at certain points reaches again the value of maximum of the region enclosed by the secondary, thus marking the outer boundary of flux linking with the primary circle alone (F_p) and of the flux linking with both turns ($+ F_m$).

Fig. 3 gives voltage distribution in case the inner circle is excited and the outer short-circuited.

W. V. Lyon: The method of analyzing the performance of a

transformer that Mr. Dahl outlines has some interesting possibilities when applied to three-circuit transformers. It seems to me that it makes clearer some points that Mr. Boyajian brings up in his recent paper on the theory of such transformers.[3]

When three circuits are magnetically coupled the instantaneous terminal potential of one of them may be equated to the sum of four components.

$$v_1 = r_1 i_1 + L_1 \frac{d\,i_1}{d\,t} + M_{12} \frac{d\,i_2}{d\,t} + M_{13} \frac{d\,i_3}{d\,t} \qquad (1)$$

The difficulty met in handling this equation is due to the fact that with an iron magnetic circuit the inductances, both self and mutual, are variables, being functions of the currents. As far as the solution of a great number of problems goes, however, this difficulty can be removed entirely by the following device. While the principle of the device is old, the way of presenting it is not so common, especially in the case of transformers with three windings. The magnetic flux distributions which account for the self and mutual inductances may be divided into two components. By far the greater portion of the flux is confined to the iron core, but a smaller part exists wholly or partially in air. This smaller part, however, determines almost entirely the operating characteristics of the transformer. This thought is interesting.

At this point we will assume that the flux that is wholly within the iron core depends only upon the value of the ampere-turns producing it, and is entirely unaffected by the position of these ampere-turns with respect to the core. While this is not precisely true the error must be very small. That is to say, this flux that is wholly within the iron is the same whether produced by a given number of ampere-turns in circuit one, two, or three. Let M be the value of inductance assigned to each circuit on account of this flux. This inductance is variable. The remainder of the flux due to any of the circuits is wholly or partly in air and for this reason is essentially proportional to the current in the circuit. In all that follows we will assume that each of the three circuits has the same number of turns. The method of treatment when the number of turns is different is well known. Thus if we subtract from the self and mutual inductances given in equation (1) the inductance M the result in each case will be an inductance of *constant* magnitude, being due to flux that exists wholly or partly in air. Equation (1) becomes

$$V_1 = r_1 i_1 + (L_1 - M)\ \frac{d\,i_1}{d\,t} + (M_{12} - M) \frac{d\,i_2}{d\,t}$$

$$+ (M_{13} - M) \frac{d\,i_3}{d\,t} + M \frac{d}{d\,t} (i_1 + i_2 + i_3)$$

The last component is the electromotive force produced in each of the windings by the action of the flux that exists wholly in the iron. Hereafter we will represent it by the letter e, or E, if the equation is written in the vector form. Following the nomenclature that Dahl uses we will write

$$(L_1 - M)\ \ \frac{d}{d\,t} = j\,x_{11}$$

$$(M_{12} - M) \frac{d}{d\,t} = j\,x_{12}$$

and

$$(M_{13} = M) \frac{d}{d\,t} = j\,x_{13}$$

So that we will now write equation (1) thus:

$$\overline{V}_1 = (r_1 + j\,x_{11})\,I_1 + j\,x_{12}\,I_{12} + j\,x_{13}\,I_3 + E \qquad (2)$$

Likewise

$$\overline{V}_2 = (r_2 + j\,x_{22})\,I_2 + j\,x_{12}\,I_1 + j\,x_{23}\,I_3 + E \qquad (3)$$

and

$$V_2 = (r_3 + j\,x_{33})\,I_3 + j\,x_{13}\,I_1 + j\,x_{23}\,I_2 + E \qquad (4)$$

x_{11} is the self reactance of circuit (1) due to flux that is wholly or partly in air. It is thus a constant quantity. Similarly x_{12} is the mutual reactance between circuits (1) and (2) due to flux that is wholly or partly in air. It is likewise a constant quantity. The meaning of the other reactances x_{22}, x_{33}, x_{23} and x_{13} is at once evident. In order to proceed with the problem effectively and without too much difficulty it is necessary at this point to assume that the sum of the currents in the three circuits, that is the net magnetizing current, is insignificant in comparison with the individual currents themselves. This assumption limits the scope of the solution, but with about full-load current in the circuit it is nearly true. At any rate it is a customary assumption and need cause no concern. Thus we will write equation (5) as

$$I_1 + I_2 + I_3 = 0 \qquad (5)$$

Equations **2, 3, 4** and **5** are fundamental in determining the operation of three-circuit transformers.

The voltage drop between the terminals of circuits (1) and (2) *i. e.* $(V_1 - V_2)$ is, if it is noted that $I_3 = -I_1 - I_2$

$$V_1 - V_2 = [r_1 + j\,[(x_{11} - x_{12} + x_{23} - x_{13})]$$
$$I_1 - [r_2 + j\,(x_{22} - x_{12} - x_{23} + x_{13})]\,I_2 \qquad (6)$$

Similarly

$$V_2 - V_3 = [r_2 + j\,(x_{22} - x_{23} - x_{12} + x_{13})]\,I_2$$
$$- [r_3 + j\,(x_{33} - x_{23} + x_{12} - x_{13})]\,I_3 \qquad (7)$$

Also

$$V_3 - V_1 = [r_3 + j\,(x_{33} - x_{13} + x_{12} - x_{23})]I_3$$
$$- [r_1 + j\,(x_{11} - x_{13} + x_{23} - x_{12})]\,I_1 \qquad (8)$$

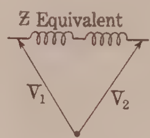


FIG. 4

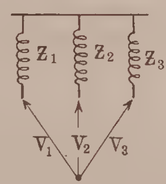


FIG. 5

It will be noted that these last three equations may be written as follows:

$$V_1 - V_2 = Z_1\,I_1 - Z_2\,I_2$$
$$V_2 - V_3 = Z_2\,I_2 - Z_3\,I_3$$
$$V_3 - V_1 = Z_3\,I_3 - Z_1\,I_1$$

The impedances Z_1, Z_2 and Z_3 in these equations are the same as Z_A, Z_B and Z_C that Boyajian uses. In the same way that a two-circuit transformer may be represented by a single coil as in Fig. 4 so a three-circuit transformer may be represented by three coils as in Fig. 5.

Equations (6), (7) and (8) throw some interesting light on the composition of the impedances that are associated with the three equivalent coils shown in Fig. 5. *e. g.* $x_{11} - x_{12}$ is the leakage reactance between circuits (1) and (2) while $x_{11} - x_{13}$

3. Theory of Three-Circuit Transformer, A. Boyajian. A. I. E. E. JOURNAL, April 1924, p. 345.

is the leakage reactance between circuits (1) and (3). The equivalent reactance of circuit (1) is the leakage reactance of (1) with respect to (2) plus the differential effect of (3) upon (1) and (2). If the third circuit were symmetrically located with respect to the other two circuits its mutual effect upon each would be the same, x_{23} would equal x_{13} and the equivalent reactance of (1) would be its leakage with respect to (2) alone. Or, if the third circuit did not carry any current the terms x_{23} and x_{13} would not enter into the equivalent reactance of the first circuit. This also appears if in equation (6) I_2 is equal to $-I_1$, *i. e.* $I_3 = 0$. It will be seen that the drop between the first two circuits is then

$$V_1 - V_2 = [r_1 + j(x_{11} - x_{12}) + r_2 + j(x_{22} - x_{12})]\, I_1$$

Now it is evident that it is only when $x_{11} = x_{22}$ that the leakage reactance of (1) with respect to (2) is equal to the leakage reactance of (2) with respect to (1). Again, if it is possible to arrange the circuits so that the mutual reactances between circuits (1) and (2) and between (1) and (3) are relatively large in comparison with the mutual reactance between (2) and (3) it may be that the equivalent reactance of circuit (1) will be negative. Boyajian mentions this.

If one or two of the three circuits delivers power to a load to which constants R and X may be assigned the terminal potential of the circuit may be replaced by $-I\,(R + jX)$ *e. g.* in the case of a load on circuit (3) equation (4) may be written:

$$I_3\,(R + jX + r_3 + j\,x_{33})\,I_3 + j\,x_{13}\,I_1 + j\,x_{23}\,I_2 + E = 0$$

In this way it becomes a simple matter to determine the power currents in each of the windings of a three-circuit transformer.

Another even more interesting point is the operation of three-circuit transformers on three-phase circuits. In this case the third circuits of each transformer are usually connected in delta and spoken of as the tertiary delta. One of the principal reasons for this is to provide a sure path for the third harmonic exciting current if the other windings are both connected in Y. The tertiary Δ is also used to supply power, often at a relatively low voltage. The general method of analysis is as follows: Write the voltage equations similar to equations (2), (3) and (4) for each winding of each transformer; nine equations in all. Add the voltages across the three windings numbered (1) and divide by 3. By definition this is the zero-sequence voltage in the first winding[4]. This gives

$$V_{10} = (r_1 + j\,x_{11})\,I_{10} + j\,x_{12}\,I_{20} + j\,x_{13}\,I_{30} + E_0 \qquad (9)$$

This assumes that the three transformers are in all essential respects identical. The added subscript 0 signifies that the quantity is the zero-sequence component. Likewise, we may write

$$V_{20} = (r_2 + j\,x_{22})\,I_{20} + j\,x_{12}\,I_{10} + j\,x_{23}\,I_{30} + E_0 \qquad (10)$$

$$V_{30} = (r_3 + j\,x_{33})\,I_{30} + j\,x_{13}\,I_{10} + j\,x_{23}\,I_{20} + E_0 \qquad (11)$$

If the third windings form the tertiary delta, V_{30} is zero. This gives a useful relation for E_0 which may be substituted in the other equations (9) and (10). Making this substitution gives

$$V_{10} = (r_1 + j\,x_{11} - j\,x_{13})\,I_{10} + j\,(x_{12} - x_{23})\,I_{20} - (r_3 + j\,x_{33} - j\,x_{13})\,I_{30} \qquad (12)$$

and

$$V_{20} = (r_2 + j\,x_{22} - j\,x_{23})\,I_{20} + j\,(x_{12} - x_{13})\,I_{10} - (r_3 + j\,x_{33} - j\,x_{23})\,I_{30} \qquad (13)$$

We also have the general relation that

$$I_{10} + I_{20} + I_{30} = 0 \qquad (5)$$

Let us consider a few of the cases that may commonly arise.

1. Primaries and secondaries in Δ.

In this case $V_{10} = 0$ and $V_{20} = 0$ and the only values of the zero-sequence currents that will satisfy these conditions are zero. That is, there can be no zero-sequence load current in any of the windings under any condition even if it should exist in some unbalanced Δ-connected load, as it might. Or, it may be said that any current that may exist in either of the other deltas can only effect the current in the tertiary delta to a minor degree. That is, additional current in either delta will probably produce a small change in the terminal potentials of the tertiary windings and so alter the currents they may be delivering. Other than this the tertiary current is not affected. Indeed, as is well known, it is only when there is the possibility that the primary or secondary may carry zero-sequence currents that there can be produced any important modification of the tertiary currents, except, of course, as the load directly connected to the tertiary windings is changed.

2. Primaries in Δ, secondaries in Y with neutral grounded and with a current to ground of $3\,I_G$. In this case the zero-sequence current in the secondary is I_G and from equation (5)

$$I_{10} + I_{30} = -I_G$$

Since the primaries are in Δ, $V_{10} = 0$ and we thus have

$$(r_1 + j\,x_{11} - j\,x_{13})\,I_{10} + j\,(x_{12} - x_{23})\,I_G - (r_3 + j\,x_{33} - j\,x_{13})\,I_{30} = 0$$

Eliminating I_{10} from three equations gives

$$I_{30} = -I_G \frac{Z_1}{Z_1 + Z_3}$$

For the meaning of Z_1 and Z_3 see equations (6,) (7), and (8) and the three following ones. That is, the total current to ground divides between the primary and tertiary as it would between two impedances Z_1 and Z_3 connected in parallel. There are also the positive- and negative-sequence currents. But they are equal and opposite in the primary and secondary just as if the tertiary were not present. The zero-sequence component in the secondary voltages is from (13)

$$V_{20} = \frac{Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1}{Z_1 + Z_3}\; I_{20}$$

For the meaning of these impedances see equations (6), (7) and (8) and the three following ones.

Another interesting point about this connection is that the third-harmonic component of the exciting current divides between the primary and tertiary but not in the same proportion as do the load currents. Since in this case the secondary can carry no-third harmonic exciting current,[5] it is without effect on its division between the primary and tertiary, and the impedances that are involved are the true leakages between these windings. The ratio of the third-harmonic components is:

$$\frac{I_3}{I_1} = \frac{r_1 + j\,3\,(x_{11} - x_{13})}{r_3 + j\,3\,(x_{33} - x_{13})}$$

In the first case, however, in which all of the windings are in Δ, the third-harmonic components of the exciting current will divide between all three windings inversely as their third-harmonic impedances. That is the third-harmonic components divide as:

$$\frac{I_1}{r_1 + j\,3\,(x_{11} - x_{13} + x_{23} - x_{12})} = \frac{I_2}{r_2 + j\,3\,(x_{22} - x_{23} - x_{12} + x_{13})} = \frac{I_3}{r_3 + j\,3\,(x_{33} - x_{13} - x_{23} + x_{12})}$$

3. Primaries in Y, secondaries in Y with neutral grounded.

In this case the sum of the primary currents must be zero and I_{10} is thus equal to zero. From this I_{30} equals $-I_{20}$ which is one-third of the current to ground. Again there are also positive- and negative-sequence currents of the same magnitude

4. Methods of Symmetrical Co-ordinates Applied to the Solution of Polyphase Networks. C. L. Fortescue, A. I. E. E., TRANSACTIONS, 1918, Vol. XXXVII, p. 1027.

5. The secondary terminals are assumed to be free.

which are equal and opposite in the primaries and secondaries but which do not exist in the tertiaries. In this case grounding the generator neutral has no effect on the current distribution since the generator is otherwise insulated from the secondaries. The displacement of the primary neutral, viz. V_{10}, is from equation (**12**)

$$V_{10} = I_{20} Z_3$$

The displacement of the secondary neutral is

$$V_{20} = I_{20} (Z_2 + Z_3)$$

4. Primaries in Y with neutral grounded; secondaries in Y with neutral grounded; generator neutral also grounded. If there is no impedance between the generator and the primaries and the generator is balanced, the zero-sequence primary voltage is zero. That is $V_{10} = 0$. Thus we have: (see equation (**12**)).

$$(r_1 + j\, x_{11} - j\, x_{13}) I_{10} + j\, (x_{12} - x_{23}) I_{20} - (r_3 + j\, x_{33} - j\, x_{13}) I_{30} = 0$$

also

$$I_{10} + I_{20} + I_{30} = 0$$

But $I_{20} = I_G$ where $3\, I_G$ is the current to ground on the secondary side. Solving these relationships gives as in case 2,

$$I_{30} = - I_G \frac{Z_1}{Z_1 + Z_3}$$

The displacement of the secondary neutral or the zero-sequence component of the secondary voltages is the same as in case 2 if there is no impedance between the generator and the primaries.

If there are equal line impedances of Z between the generator

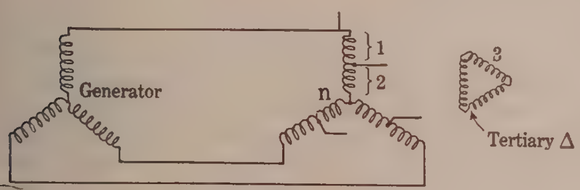


Fig. 6

and the primaries and an impedance of Z_n between their neutrals the current in the tertiary is

$$I_{30} = - I_G \frac{Z_1 + Z + Z_n}{Z_1 + Z + Z_n + Z_3}$$

The general effect of this is to increase the tertiary current. If there is any unsymmetry in the lines between the generator and the primaries the solution is somewhat more difficult involving as it does the positive- and negative-sequence currents. For in this case a positive sequence load current will give zero-sequence line drop due to the negative-sequence component of the line impedance. Grounding the neutral of a Y-connected system has of itself no effect in determining whether or not there is a zero-sequence component in the Y voltages, for it is possible even with the neutral grounded that the sum of the Y-voltages should not be zero.

There are several interesting cases involving auto-transformers,[6] of which we will consider three. The fundamental equations are now in slightly different form. Refer to Fig. 6 herewith. All of the resistances and reactances will be given on the basis of a transformer which has the same number of turns in windings (1), (2) and (3). The voltages in the individual windings are given in equations (**2**), (**3**) and (**4**). The primary potential, V_{1n}, is however V_1 plus V_2 and is

$$V_{1n} = I_1 (r_1 + j\, x_{11} + j\, x_{12}) + I_2 (r_2 + j\, x_{22} + j\, x_{12}) + I_3 (j\, x_{13} + j\, x_{23}) + 2\, E$$

Eliminating E as before gives

$$V_{n0} = I_{10}(r_1 + j\, x_{11} + j\, x_{12} - j\, 2\, x_{13}) + I_{20}(r_2 + j\, x_{22} + j\, x_{12} - j\, 2\, x_{23}) - I_{30} (2\, r_3 + j\, 2\, x_{33} - j\, x_{13} - j\, x_{23})$$

Substituting the relation that $I_{20} = - I_{10} - I_{30}$ we have

$$V_{n0} = I_{10} (Z_1 - Z_2) - I_{30} (Z_2 + 2\, Z_3)$$

If both the generator and transformers are grounded and there is no impedance between the generator and the transformers and the generator voltages are balanced V_{n0} equals zero, and

$$I_{30} = I_{10} \frac{(Z_1 - Z_2)}{Z_2 + 2\, Z_3}$$

Thus if the tertiary is symmetrically located with respect to both of the other windings of the auto-transformer and they themselves are symmetrically located with respect to the iron core the tertiary will carry no current since in this case Z_1 and Z_2 are equal. If, however, the generator is unbalanced or there is impedance between it and the transformer, the tertiary will carry current even though the windings are symmetrically located as described.

In case the generator is not grounded the zero-sequence current I_{10} is zero and I_{30} equals $- I_{20}$, that is, it is one-third the current flowing into the neutral of the transformers. The displacement of the transformer neutral in this case is

$$V_{n0} = I_{20} (Z_2 + 2\, Z_3)$$

If the generator is grounded but the neutral of the transformers is not grounded, the zero-sequence current in the tertiary must be equal and opposite to the zero-sequence current in the primary since $I_{20} = 0$. That is it is one-third of the current to ground either at the generator or load. The displacement of the transformer neutral is now

$$V_{n0} = I_{10} (Z_1 + 2\, Z_3)$$

The performance of the four-circuit and, in general, of the n-circuit transformer can be calculated by the same methods. When the transformer has more than three circuits little, if anything, is gained by attempting to represent it by an equivalent net work.

Using the same nomenclature as before we may write:

$$V_1 = I_1\, (r_1 + j\, x_{11}) + j\, x_{12}\, I_2 + j\, x_{13}\, I_3 + j\, x_{14}\, I_4 + E \qquad (14)$$

$$V_2 = I_2\, (r_2 + j\, x_{22}) + j\, x_{12}\, I_1 + j\, x_{23}\, I_3 + j\, x_{24}\, I_4 + E \qquad (15)$$

$$V_3 = I_3\, (r_3 + j\, x_{33}) + j\, x_{13}\, I_1 + j\, x_{23}\, I_2 + j\, x_{34}\, I_4 + E \qquad (16)$$

$$V_4 = I_4\, (r_4 + j\, x_{44}) + j\, x_{14}\, I_2 + j\, x_{24}\, I_2 + j\, x_{34}\, I_3 + E \qquad (17)$$

Also

$$I_1 + I_2 + I_3 + I_4 = 0 \qquad (18)$$

These five fundamental equations may be handled by a variety of ways. Since there is some advantage in having them in symmetrical form we will use the following method of elimination. First eliminate E by taking successive differences. Then eliminate I_4 from the first difference, I_1 from the second difference and I_2 from the third difference. These three equations together with equation (**18**) are sufficient to determine the currents in any case. If it is of any advantage, the loads on any of the windings may be replaced by their equivalent impedances, in which case the terminal voltages of these circuits will of course be taken as zero. We thus have:

$$V_1 - V_2 - I_1\, [r_1 + j\, (x_{11} - x_{12} - x_{14} + x_{24})] - I_2 [r_2 + j\, (x_{22} - x_{12} + x_{14} - x_{24})] + j\, (x_{13} - x_{23} + x_{24} - x_{14})\, I_3 \qquad (19)$$

$$V_2 - V_3 = I_2\, [r_2 + j (x_{22} - x_{23} - x_{12} + x_{13})] - I_3\, [r_3 + j\, (x_{33} - x_{23} + x_{12} - x_{13})] + j (x_{13} - x_{34} + x_{24} - x_{12})\, I_4 \qquad (20)$$

$$V_3 - V_4 = I_3\, [r_3 + j (x_{33} - x_{34} - x_{23} + x_{24})] - I_4\, [r_4 + j\, (x_{44} - x_{34} + x_{23} - x_{24})] + j\, (x_{24} - x_{14} + x_{13} - x_{23})\, I_1 \qquad (21)$$

and the relation that

$$I_1 + I_2 + I_3 + I_4 = 0 \qquad (18)$$

6. Performance of Auto-Transformers with Tertiary Windings under Short-Circuit Conditions. J. Mini, Jr., J. L. Moore, R. Wilkins. A.I. E.E. Transactions 1923, page 1060.

An examination of these equations shows some interesting facts in regard to the impedances. In the first equation $r_1 + j(x_1 - x_{12} - x_{14} + x_{24})$ is the impedance that would be assigned to the first winding if the first, second and fourth windings were considered as a three-circuit transformer. We will represent this by Z_{124}. The impedance $r_2 + j(x_{22} - x_{12} - x_{14} - x_{24})$ is that which would be assigned to the second winding if the first, second and fourth were considered as a three-circuit transformer. We will represent this by Z_{214}. The first subscript shows to which winding the impedance is attached. The second and third subscripts indicate which of the other windings are grouped with the first to form a three-circuit transformer. The order of the second and third subscripts is unimportant; that is, there is no difference between Z_{124} and Z_{142}. It will also be noticed that the coefficient of I_3 in the equation (19) is $Z_{213} - Z_{214}$, that the coefficient of I_4 in equation (20) is $Z_{342} - Z_{312}$ and that the coefficient of I_1 in equation (21) is $Z_{413} - Z_{423}$. Thus the equations of differences may be written as follows:

$$V_1 - V_2 = I_1 Z_{124} - I_2 Z_{214} + I_3 (Z_{213} - Z_{214}) \quad (22)$$

$$V_2 - V_3 = I_2 Z_{231} - I_3 Z_{321} + I_4 (Z_{342} - Z_{312}) \quad (23)$$

$$V_3 - V_4 = I_3 Z_{342} - I_4 Z_{432} + I_1 (Z_{413} - Z_{423}) \quad (24)$$

There are some other interesting relations between these impedances.

For example,

$$Z_{124} - Z_{123} = - Z_{214} + Z_{213}$$

$$Z_{134} - Z_{132} = - Z_{314} + Z_{312}$$

$$Z_{421} - Z_{423} = - Z_{241} + Z_{243}$$

The values of these impedances can be determined by measurement if voltage is applied to one winding and *one* of the other windings is short-circuited. If, for example, Z_{12} is the leakage impedance of the first and second windings when neither of the others carry current, then it follows[3] that:

$$Z_{123} = \frac{Z_{12} + Z_{13} - Z_{23}}{2}$$

O. G. C. Dahl: I first want to discuss the paper by Mr. Boyajian. Mr. Boyajian states that the separate leakage reactance of one winding of a transformer is not a definite quantity. It seems to me, however, that before we make any attempt to determine whether leakage reactance is an explicit quantity or not, we ought to have an accepted definition of what we mean by the term leakage reactance. Leakage reactance of one winding with respect to another ought, in my opinion, to be the reactance caused by the part of the flux set up fully or partly in air by a current in the first winding which does not produce any linkages whatever with the second winding. I believe that on the basis of this definition, the separate leakage reactance of a winding is a perfectly definite quantity and does not in any manner depend upon the connections or the load conditions.

Of course, this reactance is not the reactance which should be assigned to a winding in a three- or four-circuit transformer when more than two of the windings carry current. The reactance of a winding in this case is a leakage reactance in the sense that it is caused by fluxes which do not exist exclusively in the core. These fluxes, however, are not entirely leakage fluxes according to the definition given above. They are partly mutual fluxes, and give rise to mutual reactances ("mutual leakage reactances") which enter as a part of the total or effective reactances. This idea, I think, is very clearly brought out in the discussion by Prof. Lyon.

Mr. Boyajian makes use of the classical representation of the two-circuit transformer and states that the splitting of the reactance into primary and secondary has no meaning unless the circuit representing excitation is considered. It should be noted that such a three-circuit network is not an *exact* representation of a two-circuit transformer, although it represents the transformer very closely.

Let us assume then that Fig. 3 in Mr. Boyajian's paper represents a two-circuit transformer. According to the classical theory the voltage across the excitation impedance (Z_3) should equal the voltage induced in the windings by the flux which exclusively exists in the core (usually called the mutual flux). If this is assumed and the network is analyzed on the three-circuit basis, it can be shown that the presence of the fictitious excitation circuit does not affect the distribution of reactance between primary and secondary. Considering the currents positive when flowing toward the common point, the equations for a three-circuit transformer are:

$$V_1 = (r_1 + j x_{11}) I_1 + j x_{12} I_2 + j x_{13} I_3 + E \quad (1)$$

$$V_2 = (r_2 + j x_{22}) I_2 + j x_{12} I_1 + j x_{23} I_3 + E \quad (2)$$

$$V_3 = (r_3 + j x_{33}) I_3 + j x_{13} I_1 + j x_{23} I_2 + E \quad (3)$$

$$I_1 + I_2 + I_3 = 0 \quad (4)$$

The reader is referred to Prof. Lyon's discussion for a complete explanation of the symbols. Equation (4) signifies that the exciting current is neglected in the three-circuit transformer, while for the two-circuit transformer it simply indicates that the sum of the primary and secondary currents equals the current required for excitation. When these equations apply to the two-circuit transformer, evidently $V_3 = 0$. Introducing this in equation (3), the following expressions may be obtained from the equations above,

$$V_1 = Z_1 I_1 - Z_3 I_3 = [r_1 + j(x_{11} - x_{13} + x_{23} - x_{12})] I_1 - [r_3 + j(x_{33} - x_{13} + x_{12} - x_{23})] I_3 \quad (5)$$

$$V_2 = Z_2 I_2 - Z_3 I_3 = [r_2 + j(x_{22} - x_{23} + x_{13} - x_{12})] I_2 - [r_3 + j(x_{33} - x_{23} + x_{12} - x_{13})] I_3 \quad (6)$$

which may be written

$$V_1 = Z_3 (I_1 + I_2) + Z_1 I_1 \quad (7)$$

$$V_2 = Z_3 (I_1 + I_2) + Z_2 I_2 \quad (8)$$

The term $Z_3 (I_1 + I_2)$ represents the voltage across the excitation circuit and shall be equal to the voltage (Ec) induced in the windings of the *two-circuit* transformer by the flux exclusively existing in the core. This voltage (Ec) is not the same as the voltage (E) induced in the windings of the three-circuit transformer, and the two should not be confused.

Equations (7) and (8) may now be written

$$V_1 = Ec + Z_1 I_1 = Ec + [R_1 + j(x_{11} - x_{12} + x_{23} - x_{13})] I_1 \quad (9)$$

$$V_2 = Ec + Z_2 I_2 = Ec + [R_2 + j(x_{22} - x_{12} + x_{13} - x_{23})] I_2 \quad (10)$$

These equations must be equivalent to equations (9) and (10) in my paper on *Separate Leakage Reactance of Transformer Windings*, namely,

$$V_1 = E_1c + (R_1 + j x_{11}) I_1 + j x_{12} I_2 \quad (11)$$

$$V_2 = E_2c + (R_2 + j x_{22}) I_2 + j x_{21} I_1 \quad (12)$$

From equations (9), (10), (11) and (12) we obtain

$$(x_{23} - x_{13})(I_1 + I_2) = 0 \quad (13)$$

Since $I_1 + I_2$ is different from zero, being equal to the exciting current I_3, $x_{23} - x_{13}$ must be equal to zero. In other words we have $x_{13} = x_{23}$, which means that the mutual reactance ("mutual leakage reactance") between the fictitious excitation winding and the primary is the same as between the fictitious winding and the secondary, a result which appears entirely logical. By introducing this equality in the composite or effective reactances of the primary and secondary windings, we find that these reduce to the true leakage reactances given by my original definition. Hence, even in a two-circuit transformer the distribution of leakage reactance between primary and secondary is definite and is independent of whether or not a third circuit representing excitation is considered.

It is not improbable that the same idea might be extended to the three-circuit transformer which, when excitation is considered, represents a four-circuit problem. Also in this case it might be found that the presence of an excitation circuit does not

affect the reactances to be assigned to the three actual windings. Of course, the reactances would still be *composite* reactances, the same as would be obtained for the three-circuit transformer when excitation is neglected.

Mr. Boyajian described four tests for experimental separation of the leakage reactances in a single, two-winding transformer. Theoretically these tests all appear valid, but no doubt when applied in practise the first two will give rise to considerable inaccuracies. This is mainly due to the presence of harmonics. It will, presumably, be preferable to use the fundamental component of the voltages and currents in question. Since these fundamental quantities in each case are associated with higher harmonics of considerable magnitude, it will be necessary to take oscillograms and to separate out the fundamental by analysis. Since, as mentioned, the order of magnitude of the harmonics, particularly the third, being large as compared to the fundamental components, this separation is difficult to perform with sufficient accuracy.

These tests were tried in our Research Laboratory. However, they did not yield good results at all for the reason mentioned above, although they were all performed on 1 : 1 ratio transformers. It seems to me, therefore, that the only way in which sufficient accuracy may be obtained is by making use of such connections as will separate out currents and voltages of one frequency. This is accomplished in tests No. 3 and No. 4 where the voltages and currents theoretically should be of impressed frequency. These tests, therefore, seem entirely rational when applied to transformers of unity ratio of transformation. When used with other ratios of transformation in connection with instrument transformers, the results may easily be subject to errors, as also pointed out by Mr. Boyajian. These tests will also fail to take into account the effect of saturation on the leakage reactance, if any. Personally, I think this effect is very small.

The three-phase third-harmonic test seems to me to be the one to which the fewest objections may be raised. It determines the leakage reactances at normal (or any desired) saturation, and instrument transformers are not likely to affect the results seriously since their secondaries are connected directly to indicating meters. All doubt in regard to the calibration of the instrument transformers is thus eliminated. Of course, due to unbalance and other causes, it may be impracticable to obtain an entirely pure wave; but in any event the quantities of triple frequency which it is desired to measure will be entirely predominant and hence correct determination is highly facilitated even though oscillogram analysis may be necessary.

Mr. Boyajian's tests (1) and (2) make provisions for taking the effect of the exciting circuit into account, while his tests (3) and (4) eliminate any effect of the exciting current, because in each case the connections are such as to suppress the flux exclusively existing in the core. Since Mr. Boyajian is of the opinion that the exciting circuit affects the distribution of leakage reactance between primary and secondary, the two former tests should be expected to give results which differ from those obtained by the two latter tests. Mr. Boyajian does not mention this point at all, which to the writer seems quite important if it is assumed that the exciting circuit affects the distribution. Since, as shown, this is not the case, it would not make any difference in practise which test was employed as far as this particular point is concerned.

In connection with test No. 5 in which the Y-Δ-Δ connection is used, Mr. Boyajian presents a table giving the distribution of third-harmonic circulating current between the two closed deltas. His figures show that the distribution of this current, although to a comparatively small extent, depends upon the flux density in the core. Experiments performed in our Research Laboratory show less dependency on flux density. The table also indicates that the distribution of third-harmonic current between the two deltas to a certain extent depends on the reactance between the Y-connected winding and the two delta windings. There does not seem to be any reason why this reactance should enter into the problem at all. I am inclined to attribute the change in distribution to unbalance of the transformers rather than to any other cause. Even if the transformers are very well balanced and the ratio of transformation is uniform, it is practically impossible to avoid a small amount of fundamental in addition to the third harmonic in the closed delta circuits. According to Mr. Boyajian's sketch, Fig. 9, the third-harmonic currents were measured by inserting meters only in the closed windings. It is hardly safe to assume that the currents measured were of purely triple frequency unless this was checked by oscillograph.

Next, I want to say a few words in regard to Mr. Peters' discussion. Mr. Peters accuses me of saying that when the triple-frequency voltage, which appears when the third-harmonic current is fully suppressed, is divided by the triple-frequency leakage impedance, the triple-frequency current is obtained. I am surprised indeed that any of my statements can be interpreted in such a manner. I fully agree with Mr. Peters that the relation between the triple-frequency "open-circuit voltage" and the triple-frequency current does not follow Ohm's law. The relation, however, between the triple-frequency voltage, which is induced in the winding by the triple-frequency flux actually existing in the core, and the triple-frequency current, does follow Ohm's law.

It is well known that the third-harmonic voltage depends upon the third-harmonic current which flows. I briefly mentioned this in my paper on *Transformer Harmonics and Their Distribution* but did not discuss the mechanism of the interaction in detail. I stated, however, that it was my intention to do so in a future paper. Since this particular question, however, is brought up, I would like to say that the effect of the third-harmonic current on the third-harmonic flux and corresponding voltage may very illustratively be compared to the effect of the armature reaction in a synchronous alternator. In the latter, the excitation voltage will exist between the terminals if the machine carries no load. As soon as load is applied to the machine, however, the voltage which is induced in the winding is changed due to the effect of armature reaction, and the excitation voltage becomes entirely fictitious. If the actually induced voltage is divided by the sum of the leakage impedance and the external impedance of the machine, we obtain the current which flows in the circuit. If the synchronous impedance corresponding to the particular flux density is known, then the same current may be obtained by dividing the fictitious excitation voltage by the sum of the synchronous impedance and the external impedance. What I have done for the transformer is equivalent to the former operation. If it were possible to ascertain the value of the transformer impedance which would correspond to the synchronous impedance in the rotating machine, then the triple-frequency current could be obtained by dividing the open-circuit third-harmonic voltage by the sum of this impedance and the external impedance, if any. Of course, the internal impedance to be used in this case would depend upon and vary with the flux density, and hence with the triple-frequency current. There is a possibility that an impedance of this sort may be determined on an empirical basis, and I have looked into that question to quite an extent. However, the work has not as yet proceeded far enough, and I am not ready at this time to make a definite statement.

I agree with Mr. Peters that it was unfortunate that the ammeter had to be shifted from one of the closed deltas to the other in the Y-Δ-Δ test for determination of third-harmonic current division. I called attention to this fact in the paper. It should be noted, however, that while the meter was changed the oscillograph shunts and vibrators, which constituted the main part of the resistance in the corners of the two deltas, were never short-circuited, but always left in the circuits even when the ammeter was removed. The resistance of the shunted vacuum thermo-couple ammeter was 0.3 ohm when oscillograms Nos.

9, 10 and 13 were recorded, and 0.06 ohm when Nos. 11 and 12 were taken. Hence, the resistance of the measuring instrument was in all cases far from being of the order of magnitude of the total impedance of the winding, as Mr. Peters states. In the most unfavorable cases (oscillograms Nos. 10 and 11) the effect of a change in resistance of 0.3 ohm on the magnitude of the total impedance of the low-impedance delta winding is about 10 per cent.

I cannot give any definite reason for the discrepancy between the values of leakage impedance of winding No. 3 as determined by the two-winding and three-winding methods. As Mr. Peters points out, the one found by the latter ought to have been the smaller since it was taken with respect to winding No. 2 instead of with respect to No. 3. I do not think, however, that the difference would have to be as large as 25 per cent, even though the distance between the coils is reduced by approximately this amount. Such a direct relation between spacing and leakage reactance would exist only with a very ideal distribution of leakage flux of uniform density, which does not obtain in an actual transformer.

The discrepancy may be due to the effect of unbalance or to inaccuracies in determining the reactances by the two-winding method, or both. In the two-winding tests the third-harmonic voltages which had to be measured, particularly at the lower densities, were very small and this fact may have affected the precision of the measurements.

I fully agree in the remarks made by Mr. McCurdy. The matter of whether a leakage reactance is definite depends upon definition, a point which I have tried to amplify in my discussion of Mr. Boyajian's paper. Of course, as Mr. McCurdy also states, the leakage impedance is not the impedance which should be assigned to a winding in all cases. It depends upon connections used and the number of circuits carrying current.

Prof. Lyon's discussion of applications to three- and four-circuit transformers is very interesting and illuminating. It brings out very clearly the difference between the leakage reactance of one winding with respect to some other winding, and the reactance which has to be assigned to the same winding in case three or more windings carry current of the same frequency.

Aram Boyajian: Professors Karapetoff, Lyon, and Dahl and Mr. Peters seem to be in agreement with the speaker on the main points of the paper. Thus Prof. Karapetoff says, "In a transformer with more than two secondaries, the indefiniteness of the division of the leakage fluxes among the individual windings lies in the very nature of the phenomenon." Prof. Lyon offers a number of equations because, he says, "it makes clearer some points that Mr. Boyajian brings up in his recent paper on the theory of such transformers." Prof. Dahl is no less explicit when he says (following his equation 11) "The relative aspect of the leakage reactances should be carefully noted. The leakage reactance of a winding is not a quantity which is dependent upon and characteristic of that winding alone; it must, of necessity, be defined with respect to some other winding. This fact becomes particularly important in multi-winding transformers. Thus, in a transformer having three windings designated Nos. 1, 2 and 3, the leakage reactance of winding No. 1 with respect to winding No. 2 will be in general different from the leakage reactance of the same winding with respect to winding No. 3. . . "

Mr. Ferris' attitude is, I think, entirely reasonable. Without generalising and dogmatizing beyond his immediate problem, he states that in dealing with third-harmonic troubles it would be very desirable to formulate some sort of individual leakage reactances which could be used in the computation of residuals and third-harmonic line currents. This probably can be done to some tolerable extent, subject of course to variation with changing degree of saturation. More investigation would be desirable in this direction.

Mr. McCurdy claims that the speaker "is in error in stating that the difficulties which have arisen in dividing leakage impedances between windings are due to any lack of definiteness of the problem." What I have claimed was that (a) a single resolution of universal application is impossible, not merely difficult; and (b), that resolutions for particular applications are easy, describing half-a-dozen methods for exciting-current applications. Mr. McCurdy's interest in the subject being confined exclusively to a very definite particular problem, *viz.*, third-harmonic telephone interference, *his* difficulty was not due to the indefiniteness of the general problem, even though the general problem is indefinite. His difficulty apparently lay in the belief that the third-harmonic method is the only possible method of resolution for exciting-current applications.

Ordinarily, we speak of two kinds of transformer reactance: (1) open-circuit or magnetizing reactance, (2) short-circuit or leakage reactance. Thus, leakage reactance is the reaction of the transformer to the load currents. Still, Mr. McCurdy wants to restrict the use of the term "individual leakage reactances" only to magnetizing-current applications by saying that "it leads to confusion to call such individual impedances of three-winding transformers 'individual leakage impedances'." If the impedance offered by a transformer winding to its load current may not be called its leakage impedance, I fail to see what else may be called leakage impedance. I have justified the use of the term "leakage impedance" in connection with exciting-current applications, only by considering the excitation kv-a. as a load in a fictitious auxiliary winding.

Relative to the third-harmonic tests mentioned by the author, Mr. McCurdy asks if the effect of meter impedances and extraneous harmonics were eliminated. So far as extraneous harmonics are concerned, they were previously found to be absent by oscillographic records, and in these particular tests no oscillograms were taken. So far as meter impedances are concerned no corrections or eliminations were necessary. The test consisted in this: we had two independent windings *A* and *B* dividing between them the third-harmonic excitation of the transformer. We noted that with a certain voltage impressed on the transformer, *A* took more than half of the third-harmonic exciting current. Leaving all meter and connections absolutely unchanged, but increasing the voltage impressed on the transformer considerably, we observed that this time *B* took more than half of the third-harmonic current. This showed, regardless of meter impedances, that the division of the third-harmonic impedance between the two windings had changed in changing the impressed voltage of the transformer. The phenomenon is explainable qualitatively by a consideration of the return magnetic circuits of the two windings.

Mr. McCurdy admits that the various test methods which I have described are entirely feasible with one-to-one ratio transformers, but he overestimates the difficulties which instrument transformers would introduce, the difficulties which I have already mentioned in my paper. As against his opinion that "these methods do not have much practical importance" and that the third-harmonic method is the only way, we have Mr. Peters' opinion that "These methods are so simple and direct that chances of error are very remote." We also have Mr. Weller's statement that test methods No. 1 can be accurately reproduced, and that he has resolved experimentally the reactances of a number of potential transformers without the aid of third harmonics. Mr. Weller's results are the more significant in view of the fact that the resolution of the leakage reactances of potential transformers is much more difficult than that of power transformers.

I wish to emphasize here the inherent weakness in giving the third-harmonic method a privileged position in this resolution.

In the first place, we must recognise that third harmonics are not a necessary inherent and unavoidable accompaniment of transformer action such as resistance or reactance or magnetizing current, but they are purely incidental and even avoidable if one wishes to pay the price. Leakage reactance, on the other

hand, is an inherent accompaniment of transformer action, and is primarily formulated for, and effective to, the normal-frequency currents regardless of the presence or absence of third-harmonic phenomena. Does it appear reasonable to imply that the normal-frequency performance characteristics of the leakage reactances of the various windings cannot be determined except through the aid of the non-essential incidental third harmonics? Let us assume an air-core transformer: it certainly will have a large magnetizing current and a large leakage reactance, but no third harmonics. Does the resolution of leakage reactance become indeterminate now on account of the absence of third harmonics? Or assume an iron-core transformer: are we to think that, when it is excited at such high densities as to generate considerable third harmonics, the windings show definite individual reactances to fundamental-frequency currents; and that, when the transformer is so underexcited as to yield inappreciable third harmonics, the windings will not show definite individual reactances? Or again we ask, is the effect of the division of leakage reactance upon the normal-frequency characteristics so insignificant that it cannot be detected or measured by normal-frequency phenomena? If so, the resolution would become largely a third-harmonic phenomenon indifferent to fundamental frequency, a conclusion which the third-harmonic champions would hardly admit. We should, I believe, admit that if the resolution does make a sensible difference to fundamental-frequency characteristics, then that difference ought to give us a line on the desired resolution.

Mr. Weller mentions the interesting case of ring-wound current transformers. These constitute the simplest case for theoretical analysis. In them, all leakage reactance belongs to the outer winding, subject to a small correction due to the thickness of the inner winding.

Mr. Weller and Mr. McCurdy are right in stating that the passing reference at the end of the paragraph numbered 2 in the text should be applied to a potential transformer, not to a current transformer.

Prof. Dahl, commenting on the classical equivalent-circuit diagram of a two-winding transformer as used in my paper, says that it is not an *exact* representation, athough he is willing to tolerate it as an approximation. One would be led to infer from such a comment that Prof. Dahl's equations do not imply such a diagram and that the leakage reactances which he has formulated, and tried to determine, are not the leakage reactances shown in this diagram. As a matter of fact, this is exactly the diagram implied by the classical equations which Prof. Dahl has used, and the leakage impedances shown therein are the very impedances which he is trying to determine. The impedance links of the equivalent circuit are somewhat variable depending on the saturation of the core exactly as the self and mutual reactances used in his equations are variable with density.

This case is probably illustrative of other seeming differences between the two papers.

Prof. Dahl offers a definition of leakage reactance in the belief that by it individual reactance will become a single-valued quantity incapable of more than one interpretation. Thus, the leakage reactance of a winding is defined as the "reactance caused . . . by a current in the first winding which does not produce any leakages whatever with the second winding." Referring to the clause "caused by a current," we ask, caused by which current? Any current and every current? Or is it some particular kind of current such as exciting current or load current? If it is the latter, we then ask, which load current, the one occasioned by the load in winding X or that due to the load in winding Y? The burden of my paper was to show that the leakage reactance which a winding offers to an exciting current is different from that which it offers to a load current, similar to the fact that the total reactance which a transformer offers to exciting current is different from the total reactance which it offers to load currents, and that if the load can be applied at more than one point, the leakage reactance (for instance of the primary) is different for each different location of the load and of the secondary with respect to which the primary leakage is being considered. Thus, even the definition which Prof. Dahl offers does not necessarily make the general resolution a single-valued operation.

Prof. Dahl, like Mr. McCurdy, seems to wish to restrict the individual leakage reactances to currents considered as exciting currents. Such restriction, however, fails to reckon with the historical fact that the term "leakage reactance" is something that has always been applied exclusively to the reactance of a machine for its load current, not only in the case of transformers but also in the case of induction motors and synchronous machines. What linguistic or historical justification can there be now in trying to restrict the leakage reactances of windings to exciting current? In my treatment, the exciting current comes in as a particular kind of load, a load in an auxiliary fictitious winding, and thus takes its place alongside of other loads, coordinate with them and entitled to no unique privileges. The problem then becomes that of a three-winding or multi-winding transformer.

I am fully aware that, in contrast to the foregoing system of considering all currents as load currents, it is possible to construct an alternative system in which all currents including load currents are considered as magnetizing currents, and are thus given the same mathematical treatment as the no-load magnetizing current. The initial steps in this latter method are quite elementary, and, therefore, the first impulse of nearly everybody on first approaching the subject of three-winding transformers is to try to attack it by beginning with the familiar equations,

$$E_1 = I_1 X_1 + I_2 X_{12} + \ldots$$
$$E_2 = I_2 X_2 + I_1 X_{12} + \ldots$$

where the voltages are total voltages and the currents are the total currents in the corresponding windings, and X_1, X_2, etc., X_{12}, X_{13}, etc., are the total (magnetizing) self and mutual reactances respectively. This latter method, however, leads to great complexity and an unnecessarily burdensome system of equations; whereas, the consideration of the load currents as load currents and the reactances as leakage reactances leads to wonderful simplification of equations, even though at first it may be a little difficult to grasp the point of view. It is certain that any system dealing with multi-winding transformers and starting with total currents and magnetizing self and mutual reactances must at some stage convert into load currents and leakage reactances, to be of any practical use. All this can be accomplished directly and with very little labor and mathématics once the comprehensive physical point of view is appreciated. The work done by Mr. Peters and the writer on the theory of three-winding transformers, as well as references in American and European technical literature that have come to my attention, seem to confirm this conclusion. Judging from very old treatises on transformers, the pioneers in transformer theory used to calculate load characteristics by the aid of self inductances and mutual inductances. Later it was discovered that the idea of leakage or short-circuit reactance introduces a wonderful simplification and precision into calculations by eliminating the need of any reference to the awkward magnetizing self and mutual inductances. It appears to me, therefore, that in dealing with load-current problems, to use magnetizing self- and mutual-reactance conceptions instead of leakage-reactance conceptions, is somewhat like using the instantaneous values of currents instead of their effective values. The question here is not which is correct (because both are correct), but which is more comprehensive? Which is more practical? Which utilizes to a greater extent the accumulated technical experience of the profession? Wouldn't we handicap ourselves unnecessarily if in every problem we should start with Maxwell's fundamental equations?

The conclusion which Prof. Dahl draws from the 13 equations in his discussion is that the reactances of the three branches of the equivalent circuit are definite quantities. This conclusion

hardly needs a proof, but only this caution that this resolution refers to the exciting current because the various impedances used in the equations are the magnetizing impedances. Prof. Dahl further wishes to conclude that the resolution is independent of whether or not a fictitious excitation winding is assumed. However, whether or not a fictitious excitation-load circuit representing the kv-a. loss in the iron is expressly assumed, one is implied. For instance, if Z_1 is given as the self-inductive impedance of winding No. 1, it represents the leakage impedance between winding No. 1 and the excitation-load winding which we have postulated as hidden in the core to represent the excitation loss (kv-a., not only kw.) in the iron. Although I have called this a fictitious circuit, it is not altogether fictitious, because the core does constitute many little circuits and these may be represented by a single equivalent winding. The position and shape of this equivalent winding may not be arbitrarily assumed. It has to be such as to agree with the characteristics of each particular core.

Referring to the test methods described in my paper, Prof. Dahl states that some of them were tried out with one-to-one ratio transformers and found unsatisfactory due to the influence of the harmonics of the exciting current. It is very unfortunate that Prof. Dahl does not given any data at all, neither does he state just why the tests were considered unsatisfactory. It is possible that these tests were made after the publication of these papers and the data have not as yet been put into suitable shape for presentation. It is also possible that these tests at fundamental frequency did not check the previous third-harmonic tests and were therefore considered unsatisfactory. Now, so far as the effect of harmonics of exciting current on these tests is concerned, I think we can decide the matter rather definitely on theoretical grounds as follows:

The resolution of the normal-frequency leakage reactance by the aid of the third-harmonic test is based on the assumption that the same resolution holds at triple-frequency as at fundamental-frequency or at any other frequency. Now, if this assumption is true, that is, if all harmonics require the same resolution so that the ratio of the individual leakage reactances of the two windings is the same for all of the harmonics, then the division of the various harmonics of current between two windings ought to be the same whether one harmonic is tested or the other or whether their composite is tested, assuming that the meter impedances are not influencing the circuit conditions to any serious extent. Harmonics of exciting current could disturb the results only when the resolution of leakage reactance is different for different harmonics, and this I do not think Prof. Dahl would concede, because it would undermine the applicability of third-harmonic test results to fundamental-frequency phenomena. Furthermore, the resolution may be tested at various flux densities in the core, starting with very low densities to which harmonics are practically absent, and plotting a curve of resolution against flux density. This may then be compared instructively with the resolutions obtained by a single harmonic at the corresponding densities.

It is to be hoped that Prof. Dahl will investigate these various test methods thoroughly and that he will present his data to the Institute in another paper soon.

The curves presented by Mr. Palueff are interesting and have evidently been prepared with much care. It must be noted that he is dealing with the composite or resultant of two fluxes (produced by the magnetizing and load currents) and, therefore, the various voltages measured by the exploring coil are not directly indicative of individual reactances. Of course, so far as the individual leakage reactances (with respect to exciting current) of a transformer consisting of two circles in space are concerned, they can be very easily solved in accordance with equations **10** and **11** of my paper without having to plot any curve. It is unfortunate tht Mr. Palueff did not segregate the two components of fluxes and voltages.

Professor Karapetoff as an educator is rightfully somewhat concerned over the sense of uncertainty and indefiniteness that people may get if told of the relativity of the resolution of leakage reactance. It was attempted to guard against this opposite extreme by tabulating at the end of my paper a number of definite conclusions indicating specific applications and interpretations.

LOSSES IN IRON UNDER THE ACTION OF SUPERPOSED A-C AND D-C EXCITATIONS

(Charlton and Jackson)

Saratoga Springs, N. Y., June 25, 1925

J. D. Ball: About ten years ago I was very much interested in investigating the amount and nature of magnetic losses in iron when subjected to a superimposed a-c. and d-c. excitation. We spent three years on this investigation and collected what we could find of the data available at that time. All the results showed quite conclusively that for a given flux change due to alternating current, there was a definite increased loss in the hysteresis if d-c. flux was superimposed upon it, and the greater the superimposed d-c. excitation, the greater the loss. The same conclusion was verified by experiments made at the United States Bureau of Standards, at the Pittsfield Laboratory of the General Electric Company, and also by tests made in the Standardizing Laboratory of the General Electric Company at Schenectady. The results from the various publications studied led us to the same conclusions.

In the present paper the writers state that an attempt was made to account for the additional losses due to a superimposed d-c. excitation by a formula in which the Steinmetz equation was used with changed exponents. This is not accurate. In our mathematical equation the Steinmetz formula was left exactly as it was given by him but it was extended by adding a supplementary expression which would indicate the increased losses. It is readily seen that to be mathematically correct this additional expression must be added and cannot be multiplied; otherwise the entire expression would become irrational when the d-c. excitation is zero.

There was no certainty expressed at the time that the expression, as supplemented by ourselves, was necessarily correct, but this equation did agree with the results of various experimenters and was satisfied by the data which we obtained.

Our investigation was made for two reasons; first, to assist in the design of machines where those conditions applied, such as in the inductor generator, and in the iron losses in rotor teeth; and: second, in the hope that it would stimulate inquiry and result in the subject being studied by other investigators.

The present paper disputes the results obtained up to this time. It is not essential to defend our position taken some time ago; the only thing in which we are interested is what are the actual facts. The present results are unquestionably correct for the tests made, but I should question whether the authors had the same conditions in their circuits which they thought they had.

I am more than glad additional inquiry has been made on superimposed losses. I do not think it is fair to take the results of this paper as the results of anything except the particular circuits in which they were applied. Since the tests, as the authors are aware, have been made in accordance with what has not been considered good practise for a number of years, I feel they will agree with me on this.

Turning to the paper, the first thing is the question of taking the instrument losses from a primary coil. This was the way it was done for a good many years and up to fifteen years ago, it was considered the best way possible. The instrument losses and additional current consumed by the instruments are nicely taken care of and it is a simple matter to take out those instrument losses which can be mathematically calculated and you always get something although not always what is aimed at.

It has been shown by experimenters in magnetic materials that it is necessary to use a potential or secondary coil for a

voltage coil to measure the flux, and also to use the potential coil, either the same one or another potential coil, to excite the voltage winding of the wattmeter. I think it was Prof. Epstein who first pointed this out and the fact has been thoroughly established.

Some elaborate tests were made at the Bureau of Standards in Washington and it was pointed out by Dr. Lloyd, and afterwards by Dr. Burroughs, that it was absolutely necessary to use a potential coil to get consistent results in any magnetic testing or investigation which they attempted. That is why I was surprised in glancing over this paper to find a secondary potential coil was not used. I feel that if definite conclusions are drawn, it would be very well to check these results, using the approved method of employing a potential coil.

A second point I wish to make refers to the nature of the magnetic circuit used. Possibly I misread this; but taking Fig. 3, if this represents the same connection as shown in Fig. 1, in which there is a d-c. excitation on the center leg of a three-legged core, and another excitation, a-c. or d-c., on the outer legs, I should take exception to that method of procedure. That isn't exactly superimposing alternating current on direct current. In a three-legged core, flux does quite a number of things and it doesn't all go through the same paths.

Another point; in superimposing alternating current and direct current, I know from experience that you get wild things unless it is done in one definite manner; that is, to have the alternating current and the direct current with one winding right on top of the other, so that any leakage or trouble of any kind would have to be more or less similar.

Another point is that the results obtained from any sample except a ring sample didn't seem to be very good. True, with a ring sample the flux density is greater at the inner circumference than at the outer circumference, but corrections have been established by the Bureau of Standards. We found the only reliable method was to use a large ring in which the mean diameter of the ring was comparatively large in comparison with the width of the sheet, or the difference between the outer and inner radii of the test specimen. Even then certain corrections should be applied as pointed out by the Bureau of Standards and others.

There are at least two definite ways of superimposing alternating current and direct current: One is to subject the test specimen to alternating current and to superimpose on it a direct current in another winding immediately under or over it; another way is the step-by-step method, measuring the losses by the ballistic galvanometer. I think it would be well to check the present tests by the step-by-step method. First, a definite flux change should be assumed which would represent the iron when subjected to the a-c. excitation. The hysteresis loop should then be obtained by the well-known step-by-step method. This is the normal hysteresis loop. To obtain the effect of superimposing d-c. excitation, another loop which I have termed the "unsymmetrical loop" should be taken. This can be done by going up on the saturation curve to some point higher than the maximum of the first loop, then dropping down on the normal hysteresis loop from this second point to a point where the flux change from this new maximum is in the same amount as the total flux change in case of the first loop. Then from this new bottom point, return step-by-step to this new maximum. Rather unique figures are obtained by this method, some of which were published in 1915[1]. We invariably found that with the same flux change the area was always greater when the maximum point from which the loop started was raised. This is the same situation as when you have an a-c. excitation and superimpose upon that excitation a d-c. excitation represented by the mean density between maximum and minimum of the various loops. A study of these figures, the characteristics of any hysteresis loop, and the characteristics of any magnetization curve will show that invariably the area of the unsymmetrical loop increases with increasing mean density, the flux change remaining constant.

1. The Unsymmetrical Hysteresis Loop, by J. D. Ball, A. I. E. E. Transactions, 1915, Vol. 34, page 2693.

A. C. Lanier: The oscillographic record, Fig. 5 in this paper, seems to show a reduction in the density range as well as a change in shape of the dynamic hysteresis loop due to combined a-c.-d-c. excitation as compared with the normal loop. Both effects should increase progressively with the increase in d-c. excitation for large a-c. excitations, and both should cause a diminution in the hysteretic component of the iron loss. The effect upon the eddy-current component is less clear. With small a-c. excitations there should be no appreciable reduction in density range except for very large d-c. excitations. The area of the displaced hysteresis loop for a given density range has also been shown to increase with increasing average density. Therefore, the curves of Fig. 2 appear, reasonable.

In connection with the study of surface iron losses, the speaker has noticed that sometimes, with high average gap densities, the measured losses are less than the expected values. The magnetic structure used when these results were observed was a homopolar structure consisting of a slotted cylindrical member rotating within a smooth cylindrical member. The excitation produced radial average flux distribution with a superposed tooth ripple.

At high densities the amplitude of flux pulsation increased less with a given rise in gap density than it did at low densities. The loss increase was correspondingly lower. The seeming discrepancy is traceable to the effect of high tooth saturation which causes a departure from the straight-line relationship between the tooth-ripple density and the average gap density.

Considering these results it seems probable that if the average gap densities had been carried high enough, the flux ripple and the losses due to it might have shown actual decreases with further increase in average gap density.

O. R. Schurig: Mr. Ball called attention to the possibility of errors resulting from the method of iron-loss measurements employed by the authors, if proper corrections are not made.

It is true that the power given by direct primary measurement, that is without the use of a separate potential winding on the iron core, includes losses other than iron losses. If, however, the extra losses are evaluated and corrected for, correct iron losses are obtained. I believe the paper gives evidence to show that the proper corrections were applied and that reliable results were secured.

It must be pointed out here that the method of iron-loss measurement employing a separate potential-circuit winding on the iron core—the method advocated by Mr. Ball—also involves possibilities of grave errors. The potential-coil method is particularly subject to error where there is leakage flux between the primary (exciting) winding and the potential (exploring) winding to which the wattmeter potential circuit is connected—a well-known fact. Thus, the reliability of any test results on iron losses depends on the thoroughness with which the extra losses have been corrected, unless the circuits have been specially designed to make the excess losses negligible.

It so happens that within the last year the potential-exploring-coil method has been applied at Schenectady to iron-loss measurements with superposed d-c. and a-c. excitations; *i. e.* a series of tests similar to those presented in the Charlton and Jackson paper, but utilizing, for measurement purposes, a separate potential winding on the iron core under test. The results of these more recent tests, to be published on a future occasion, show as do those of the paper, a slightly decreasing iron loss with increasing d-c. excitation when high a-c. excitations at constant impressed a-c. voltage were employed.

K. K. Palueff: I should like to mention that if a core as used by the authors is long a certain portion of the total flux produced by windings placed on the outer legs may not reach

the center leg but take an air path for return. The same thing would be true for the flux created by the winding on the inner leg. This "stray" flux will increase as the flux density increases. Thus, the superposition of two fluxes—one created by the winding on the outer legs and another by the winding on the inner leg—may not be as complete as anticipated.

W. R. Weeks (by letter): In the measurement of iron losses under normal conditions, what is known as the Epstein circuit is used to eliminate the $I^2 R$ losses of the exciting winding and wattmeter current coils from the readings. If it is possible perfectly to interlink, the excitation coil and the exploring coil, then the readings obtained will be an accurate measure of the losses in the iron. The errors due to circuit-resistance losses will be automatically eliminated.

However, errors may be introduced if there are other circuits which produce flux that links the exploring coil but does not, at the same time, link the exciting coil. Such leakage flux between the two windings will cause errors that will be positive or negative depending on the phase relation of the leakage flux.

There are three possible conditions that may be encountered. (1) If there is no leakage between the exploring and excitation coils, the readings will be correct. (2) If there is leakage between the exploring and excitation coils, and there is no third excitation coil, the readings of the wattmeter will be low. (3) If there is leakage between the exploring and exciting coils and there is a third coil (such as the d-c. winding) which sends flux through the leakage path, the readings of the wattmeter may be high.

All of the above leakage factors are quite difficult to determine for any magnetic circuit such as that used by the authors of the paper, and I believe that using the older method which introduced additional losses, losses that could be accurately determined, was much preferable to trying to use the Epstein circuit.

The Epstein circuit would undoubtedly be better if the exciting coil were the outside strands of a cable of which the central strand was used as the exploring or potential coil.

J. E. Jackson: Mr. Ball has pointed out the fact that the paper was inaccurate as to the exact methods that had been applied in correcting the Steinmetz formula. I am sorry that the mistake was made, but it was intended mainly to indicate that an attempt of some kind *had* been made to adapt existing formulas to the case of superposed excitations.

In answer to the question of why the Epstein method was not used, it was simply because it was felt that with the facilities available, the "subtraction method" was much more reliable. Mr. Weeks has pointed out some of the difficulties encountered in the Epstein method, and, that for the very reason that no one knew what the different fluxes would do when they were superposed, it was impossible to calculate the errors to be expected. If all the leakage factors were accurately known, the calculations would still be more involved than the ones used, and there would be that much more chance of error.

Whether the two circuits used were identical in their behavior or not is still an open question, but the data showed that they were at least substantially alike. Our wattmeter method, when used in the series circuit, was felt to be correct, and the fact that the curves were practically the same when taken with the three-coil circuit tends to prove that the flux paths were very nearly identical in the two cases.

Mr. Ball stated that a study of magnetic characteristics would show that invariably, the area of the unsymmetrical loop increases with increasing mean density. I do not believe that this is necessarily true if the analysis is carried far enough. Our hysteresis loops taken with the bilateral oscillograph show clearly that the area is less at the top of a distorted loop, and a consideration of the magnetic theories of Ewing, Poisson, and others shows that this must be the case. Hysteresis is generally regarded as some sort of molecular friction, and when d-c. excitation is added to the core the molecules are lined up and held so tightly that they cannot turn over completely with the reversing a-c. flux, but only vibrate slightly. If the d-c. excitation is strong enough to hold them tightly clamped, the hysteresis loss must disappear completely. The eddy-current loss should not change at all unless the wave form changes, so the net result would be a decrease in iron losses with d-c. saturation. As a matter of fact, the wave forms do become slightly distorted, and the eddy losses tend to go up to some extent.

Our work may not be accurate in the highest degree, but we feel that it is not grossly in error, and that certainly the iron losses do not increase ten or twenty times when d-c. excitation is added, although they may change as much as 100 per cent one way or the other.

THE KLYDONOGRAPH AND ITS APPLICATION TO SURGE INVESTIGATIONS[1]

(Cox and Legg)

Saratoga Springs, N. Y., June 26, 1925

D. W. Roper: One of the first things that is necessary in order to make improvements in power cables is to know what causes the failure. A paper on dielectric losses in relation to cable failures[2] presented before the Niagara Convention outlined one cause of failure and the method of determining when such failures occur. A study of the failures on the cable system in Chicago, however, indicated that only 40 per cent of the failures of the transmission cables could be accounted for on this basis, and we had to look elsewhere for the balance.

Then it was noted that there were occasional simultaneous failures of switches in generating stations or substations and cables. There was a continuous discussion as to which was the cause and which the effect, and the cause was difficult to determine until the office cat wandered into the switch-house and came in contact with a line reactor. That gave us a very definite cause and when a cable failure occurred at the same time we knew the station trouble was the cause and the cable failure the effect.

That was verified later at another station where a rat got across the insulation of a switch connected to the generator bus and on that occasion two cable failures resulted.

The interesting part is that we know definitely that from these transient voltages cable failure is caused, and the next thing to do is to get some idea of the nature and voltage of these transients. We have been, for a number of years securing records by means of needle gaps, but it was hard to tell just what they meant. When a transient sparks across a needle gap, you know that the voltage of the transient is greater than the voltage required to spark across a needle gap, but you don't know how much greater; it may be 10 per cent greater or 100 per cent greater. But in the klydonograph we get an instrument which will tell us that particular quantity.

In the Dufour oscillograph we get an instrument which will give us more intimate information regarding the nature of these transients, their shape and their voltage. The interesting thing about these transients and their frequency is that the theoretical men tell us that high-frequency transients do not travel, and that they cannot travel on underground systems. Then we have a disturbance like this cat and the reactor performance at one place and the cable failure occurs a few miles away. They say that the transient must be due to the effect of the discharge of the magnetic energy in the transformer, but it sometimes occurs a mile or two away from a transformer, and in such a way that the only part from the switch that fails to the cable that fails is through two line reactors which are said to stamp out transient voltages of that frequency.

With the advent of these new tools, we may call them, for

1. A. I. E. E. Journal, Vol. XLIV, October, 1925 p. 1094.

2. Dielectric Losses and Stresses in Relation to Cable Failures, by D. W. Roper, A. I. E. E. Transactions, Vol. XLI, 1922, p. 547.

attacking the problem of the troubles which occur on our cables, we should be able very shortly, with the continued assistance of the companies in whose laboratories these tools have been developed, to determine first the cause of the failures of our cables and afterwards the cure.

K. B. McEachron: We have been making a few preliminary tests, using the klydonograph and we believe it will be a very useful tool. There is just one point that I wish to bring up regarding the calibration for different wave fronts in connection with the work that we have done recently.

Near the beginning of the paper it is stated that a 25-cycle wave would produce a figure of the same size as a wave of short front. We have briefly investigated the effect of using single half cycles of a 60-cycle wave so as to separate the positive and negative figures. This was done by a special synchronous switch, recording the wave form by an oscillograph. To give only one case, as an example, we found that a 60-cycle wave of 15 kv. maximum gave a negative figure with a radius of about 1 mm. while a steep-wave front impulse, about 0.01 microsecond, of the same voltage gave about 10 mm. While there may have been reflections in the impulse circuit tending to increase the voltage, we could hardly expect more than two or three times the voltage due to reflections so that it seems probable that the difference in wave front is responsible for at least a part of the change in the size of the figures.

Based on such data, I want to question the statement that the size of figure is independent of the wave front. We believe that the same size of figure may represent considerably different voltages if the wave fronts vary through a wide range.

B. E. Hagy (communicated after adjournment): It may be of interest to describe briefly the results of some recent tests on the system of The Philadelphia Electric Company in which two of the klydonograph instruments were used.

The tests were made on one line of a double-circuit, 66-kv., ungrounded, open-wire tie line between two generating stations which are about 14 mi. apart. Both lines on the transmission towers are insulated for 110 kv. and have overhead ground wires. The oil switch at the end of the line farthest away from the point where the actual switching was done remained open throughout the tests.

The purpose of the tests was to determine the transient disturbances set up on this line by normal switching operations on the system. Attempts to propagate surges on the line were made by charging electrolytic lightning arresters, by shifting load from line to line, by picking up and dropping an unloaded but fully energized line, and by changing the ratio of some tap-changing transformers at one end of the line, etc. This testing was carried on over a period of two days and several readings of value were obtained.

On one of the two days, a polyphase klydonograph instrument was located at each end of the line, the purpose being to measure the surge voltages at both the sending end and at the distant open end which were expected to be of different magnitude due to attenuation, damping, corona or other effects. On the second day, both klydonograph instruments were located at the same end of the line but on opposite sides of the line choke coil for the purpose of determining the voltage difference caused by the inductance of the coil. There were considerable differences in simultaneous readings at the two ends of the line and across the choke coil.

The highest value of surge voltage reached during the two days of miscellaneous testing was 4.3 times normal or 240 kv. crest to ground while there were several readings of over three times normal. The reading of 4.3 times normal as well as the majority of the other high readings were recorded when the unloaded but energized line was disconnected from the source by opening the high-voltage line switch.

An interesting point of information indicating desirable operating procedure is noted in comparing the results of switching on the high- and low-voltage sides of the step-up transformers. These results show that while almost no surges are produced when the switching is done on the low-voltage side, surge voltages of more than four times normal are produced when the switching is done on the line side of the transformer.

The changing of transformer ratio under load, the shifting of load at an intermediate substation, the energizing of the line and the charging of lightning arresters produced only nominal surges, which is somewhat surprising particularly with respect to the operation of charging the electrolytic lightning arresters which was expected to cause surges of fair magnitude. In some cases, the voltages built up by reflection at the distant end of the line as well as the voltage on the line side of the choke coil were simultaneously greater than the voltages on the same phase at the source end and sometimes less. Only a few of these surges were oscillatory in character and these were rapidly damped.

These tests are, of course, of different significance from those described in the paper where the usual application of the instrument was to have it connected more or less permanently to the system over a fairly long period to record normal system surges due to atmospheric conditions as well as switching while the purpose in the tests described was to reproduce several normal switching operations in a short period and in good weather for the purpose of determining the probable magnitude of switching surges in ordinary operation. Even under the less severe conditions, it will be noted that the voltages recorded are relatively greater than any previously reported. It may be that on a good many systems routine switching operations will produce surges of surprisingly high value.

The latest film-type polyphase instruments were used in these tests and the results secured and the experience with them show the device is convenient to use and gives ample voltage records whose meaning is easily interpreted.

J. H. Cox: Mr. McEachron raised two questions; one was calibration of the klydonograph when the figures begin to slide and the other was the accuracy of calibration for various frequencies or steepness of wave fronts. As brought out in the paper, when the figures begin to slide they do not behave in a consistent manner and the voltage is approaching the limit of the instrument. However, when these slides do occur there are nearly always some rays that emanate direct from the center and the length of these conforms to the calibration curve.

In the development of the klydonograph little work was done using wave fronts beyond two limits of length, that is shorter than five microseconds and longer than that given by a 25-cycle wave. Most of the work was confined between five and 200 microseconds. A great many records were taken with surges as abrupt as could be produced by ordinary means and our work leads us to believe that these conform to the calibration curve of the more tapered surges. They were not used in obtaining these curves for the reason that the voltages produced in such a circuit are indefinite. When a spark-gap is discharged into a simple circuit, as done by Mr. McEachron, you cannot say with any degree of certainty what the voltage is at any part of the circuit. It required a great amount of work to set up a circuit that did not give reflections and oscillations. Successive records taken without changing a set up did not vary as much as 1 mm. Further, when a single surge was impressed on six terminals tied together no variation could be measured.

The klydonograph was developed for the purpose of recording transients on transmission systems. It has been gratifying to find that the surges present on practical lines have a wave front between one and 200 microseconds. In this range at least the klydonograph is entirely satisfactory. It must be remembered that no greater accuracy than 15 per cent is possible in such an instrument. This is ample for practical use.

When the application is as slow as a 60-cycle or a 25-cycle wave the conductivity of the film surface has an influence. A

slight conductivity in the case of a slow application will allow some charge to leak off the electrode and thus tend to lessen the intensity of the field at the emulsion surface which is necessary to produce a figure. We have found commercial films to vary somewhat in this respect, but not enough to cause concern when dealing with surges. The performance of the instrument at commercial frequencies is not particularly important since there are more convenient methods of measuring such potentials.

A NEW METHOD AND MEANS FOR MEASURING DIELECTRIC ABSORPTION[1]

(MARBURY)

SARATOGA SPRINGS, N. Y., JUNE 25, 1925

J. B. Whitehead: We have not had sufficient recognition of the importance of dielectric absorption as a factor in the question of dielectric loss. Modern theory of dielectric behavior, such as it is, is directed more and more toward the explanation of dielectric loss in terms of dielectric absorption. That is not to say, however, that we are getting to understand the fundamental character of this loss any better, because there is no more obscure phenomenon than that of dielectric absorption.

We have Maxwell's theory of absorption but Maxwell's theory has not been confirmed by quantitative measurements, and, indeed, there are many indications that it must be modified in some way. However, the actual phenomenon itself is relatively simple; that is to say, we can make certain measurements on dielectrics which will give us certain curves, and if we express these curves in terms of mathematical functions it is possible to

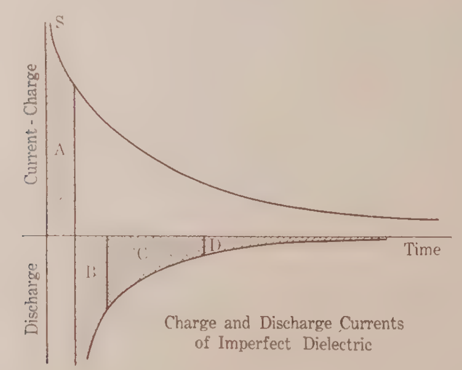


FIG. 1

substitute these functions in our simple a-c. power equations and we get expressions for dielectric loss, phase difference and specific conductive capacity, which go far toward explaining their variations with such quantities as voltage, frequency, and to somewhat less extent, the temperature. So it is particularly important that we should have a paper on this subject.

I find, however, in considering Mr. Marbury's method that it is subject to one very serious limitation. One of the best ways of representing the phenomenon of absorption is to plot a curve as in Fig. 1 between the charging current of the condenser containing the dielectric and the time; that is to say, if we take a condenser which has been lying idle a long time, and suddenly apply a continuous voltage, measuring the current, we find a curve approximately asymtotic to the axis of time, but which, in most cases, reaches a final steady value. In a few very perfect dielectrics only does the curve come down to the horizontal axis. This curve can extend over a very long period of time, days or even months.

For example, in 60-cycle circuits, we have complete reversal of voltage in a very short interval of time and consequently any influence of this absorption curve must pertain to a portion of the curve which is extremely near its starting point, S. The great trouble that has been found in linking up the phenomenon of absorption with losses as we observe them has been the difficulty of determining the shape of this curve for extremely short intervals of time.

In the cycle represented by Mr. Marbury's instrument, he charges the condenser for 1/10 sec., the quantity of charge being represented by the area A of the figure. He then discharges it for about the same interval of time (1/10 sec.) the quantity discharged being shown by area B. Now, there is a law not very generally spoken of connected with this phenomenon of absorption. This is called the "Principle of Superposition." It was first noted by Sir John Hopkinson in some of the earliest and best work that has ever been done on dielectrics, and it was confirmed beyond question by J. Curie. It states that if you start one of these absorption curves, and then make any change, whatever, in voltage, the succeeding behavior of the dielectric will be as though you superimposed upon the initial curve, the curve represented by the change of voltage when acting alone. In the figure, this means that when dielectric is short-circuited it behaves just as though we had applied a negative value of the voltage equal to the charging voltage. The discharge curve is exactly similar to the charging curve, but refers to the charging curve instead of the horizontal axis. In other words, it says the preceding state of the dielectric persists with the change in voltage applied to the initial curve, and not to the horizontal axis. So, also, the discharge curve which Mr. Marbury gets is subject to the same law.

But what does he do? He has discharge for only a period of 1/10 sec. and then allows the residual voltage to rise for a period of 9/10 sec. but then he stops! His voltage residual due to the first cycle is represented by the progressive integration of the area C; that is, all the residual due to areas B and D are not included.

If the discharge interval stops before the dielectric is completely discharged, represented by the full area under the discharge curve, he has not measured his residual voltage accurately. The observations he makes appertain to the particular cycle represented by his instrument, because his next charging cycle rises to a lower value and the successive discharge curve will also be a little less; but something more will be added to the foregoing residual. He is measuring the sum of a succession of these intervals, each one being less than the preceding one. So he is measuring something that is certainly due to absorption, but it is peculiar to the particular cycle he is using; namely, 1/10-sec. charge and discharge and a 9/10-sec. residual. The 1/10-sec. interval is of no great interest because it is not short enough for information as to 60 cycles. Hopkinson's investigations showed that a condenser, so far as the initial static charge is concerned, will be discharged in an interval in the order of a 1/17000 sec., the residual curve then starting. So in Mr. Marbury's instrument the discharge interval allows a large portion of the absorption to escape in the short circuit.

I am sure that Mr. Marbury's instrument will be of great value in testing the relative absorption properties of dielectrics, particularly those in which most of the discharge will take place within the interval of the instrument itself, but I think it ought to be clearly understood that it does not measure the true absorption curve and that what it measures is peculiar to this particular instrument.

Arnold Roth: It is interesting to note the different opinions on the importance of the losses in cables. We have worked on this question in Europe and our cable manufacturers also used to give much importance to this factor.

I should like to point out the difference in the importance of these losses in two kinds of materials, namely, (a) cable with relatively moderate outside temperature, (about 40 deg. cent.), and (b) materials which I should like to call "high-loss" materials, like bakelite, shellac, paper, etc., in oil of high temperature, (70 to 80 deg. cent.). The importance of the losses for

1. A. I. E. E. JOURNAL, Vol. XLIV, July, p. 718.

those two kinds of materials from the practical point of view is quite different.

To make it clear, I should like to speak of two kinds of breakdowns. On one side we have what we call the "real electrical" breakdown. It is known to all of us. It occurs in one-minute tests, one-second tests or 1/10-second tests. Its physical details are not explained. On the other side there is another kind of breakdown, which I should call "heat breakdown" or "loss breakdown." It was explained by Steinmetz, Wagner, Dreyfuss and others, and is based only on the specific losses and the heat conductivity. You will remember that in insulating materials there are losses, and the losses increase very fast as the temperature increases. If you have some kinds of material and apply a voltage, it will create losses and the losses are transformed into heat. The heat makes the temperature rise, and you may reach a balanced state or an unbalanced state, depending entirely upon the voltage impressed.

This effect might be illustrated by the curves in Fig. 2 herewith, representing losses plotted against time. Curve E_1 refers to a voltage E_1; Curve E_2 to a somewhat higher voltage E_2. The object measured might be a bushing of the paper type (with or without condenser layers). In the first case, an equilibrium is reached after some hours; in the second case breakdown occurs.

It is possible to predict the voltage at which this breakdown occurs before having made any tests, provided you know the specific losses of the material and the heat conductivity. An accuracy of 10 to 15 per cent is possible. I say that in order to show that this phenomenon is not simply an assumption but that it is a calculable fact.

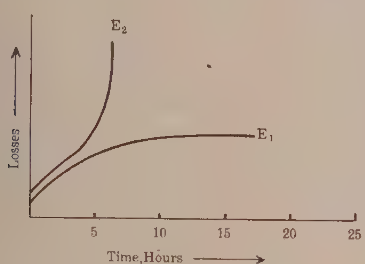


Fig. 2

Now, to get back to the point from which I started: I repeat that there are two kinds of breakdown voltages which may exist; namely, the heat breakdown voltage, due only to the losses, and the electrical breakdown voltage which, so far as known today, has no direct relation with the losses. In your cables, you have now very low losses and if you calculate the heat breakdown voltage for cables, you will see that you will come to about 180,000 volts in sustained service. You will see that today this heat breakdown voltage is of no importance whatsoever in connection with cables.

I do not wish to be misunderstood. Although the direct effect of the losses does not enter into consideration, that does not mean that loss measurements are of no importance. Loss measurements do give very interesting indications about moisture, regularity of manufacturing processes and so on.

The heat breakdown voltage is quite another thing in bakelite. You are using it in hot oil in transformers; it may be at 60 to 90 deg. cent. In addition there are the specific losses of the material itself, so that you get there a limiting voltage of 60 kv. It might vary from 40 to 70 kv. You may be astonished because I apply such high voltages to bakelite. In speaking of those breakdown voltages, I am speaking of the case where you have only a unidirectional flow of heat. In a bushing you may have a dissipation of heat in the direction of the axis also and the tension will be higher than that.

You see now that the electrical breakdown voltage for the cable is below this heat breakdown voltage and so the heat breakdown voltage is not of interest for cables. But it is quite a different thing for bakelite. For bakelite the electrical breakdown voltage is above 60 kv., so the heat breakdown voltage is interesting. I know very many cases of commercial design where the heat breakdown is the governing factor.

Delafield DuBois: Mr. Marbury's paper, and Fig. 8 in particular, add to the data that we already have linking absorption, dielectric phase difference and dielectric loss with moisture. Now the behavior of moisture in a dielectric under electrical stress, and particularly in a fibrous dielectric, is a most complex phenomenon. The moisture is strongly held by surface tension but is acted on by electrical forces tending to form it into conducting paths. Complicating this is the fact that the passage of current through these paths tends to disrupt them by heat generated in the paths.

If we had a dielectric containing a high resistance path embedded in it and partially bridging it, we would have the equivalent of the model condenser shown in Fig. 4 of the paper, and such a model would give a residual voltage curve as given in Fig. 6. But if this conducting path were a path of moisture it would not remain a fixed path of constant resistance, but would be constantly changing in length and resistance and interconnections with other moisture paths under the application and removal of voltage, and we should no longer expect a curve as Fig. 6. There are so many factors affecting this change that it is difficult to give them all proper weight in drawing conclusions. But, referring now to Fig. 10, it would seem that above a certain voltage the moisture paths, if we may consider them such, tend to increase in their effective resistance, acting to improve the dielectric. It is as if the dielectric became dryer with the increase of voltage.

It is obvious that for a higher voltage the conducting paths carry more current, and it does not seem unlikely that it is this current, dispersing the moisture paths, that is responsible for the shape of the curves of Fig. 10.

W. F. Davidson: Mr. Marbury's paper calls our attention to a very important phase of insulation behavior and one which gives promise of telling much about the fundamental behavior of electrical insulating material. The paper also presents a very interesting shop method for determining certain aspects of dielectric absorption, but I think it would be a mistake to classify the method as truly scientific.

Towards the end of the paper the author calls attention to an apparent saturation of the dielectric. In an effort to explain this we find a disconcerting lack of detailed information as to the apparatus used and the test procedure. For instance: the diagram of connection indicates a 110-volt d-c. supply for charging the condenser and we are without information as to the means used for varying the voltage in the individual tests. If this is done by means of a series resistance, certain results would be expected, while if it is done by varying the voltage of a battery with low internal resistance, the results would have a somewhat different characteristic. Furthermore we have no exact data as to the duration of the contact, either for the purpose of charging or for the purpose of discharging the condenser. An effort to determine this time by scaling from the drawing indicates that the contact has a duration in the order of 0.03 seconds, which can hardly be considered as a quick short circuit. Neither can the 60-ohm resistance be placed in the discharge circuit, be called low resistance, although it is quite permissible to use this sort of method for shop work.

In the early part of this paper the author referred to the "inherent uniformity" of impregnated paper, but I fear that his statements are somewhat misleading and a little too optimistic. Those of us who have had experience with high-voltage cable with impregnated-paper insulation fully realize that this material does not have an inherent uniformity; if it did have, many of the difficulties of the cable manufacturer would be things of the

past. I must also question the thoroughness with which oil impregnates the material, for numerous observations have indicated that the thoroughness of impregnation depends in a very large measure on the type of fibre from which the paper is made. Probably Mr. Marbury's statement is quite correct for the type of paper used in manufacturing condensers, but it is hardly correct for some sorts of paper which have been suggested for use in high-voltage cable.

In the last paragraph of his paper the author makes the prediction that a study of absorption may afford a means of predicting cable failure in operating systems. A method of cable testing based upon this idea was described before the Institute in 1923 by Messrs. Phelps and Tanzer[2] and had been further developed by several operating companies. In a discussion of a paper on testing cable by Mr. Lee[3] and presented at the Midwinter Convention of this Institute several aspects of the problem were discussed. Special high-speed curve-drawing instruments for recording the data were described and some of the results presented.

Due to the large amounts of energy involved the "discharge and recovery system" such as used for small condensers is very difficult to handle on long cable. Better results seem to be obtained by observing the characteristic during the period of charge. In addition to the advantage just mentioned for the charging system as distinguished from the discharge and recovery systems, there is the point that the readings are somewhat less influenced by the previous history of the cable. This is of great importance since the absorption of many of our cables is of very large magnitude and unless long times are allowed to elapse between successive tests the readings on any one test may be largely influenced by the preceding test value.

Probably the value of Mr. Marbury's paper could be very considerably increased if he could include some data taken with a electrostatic oscillograph showing the voltage across the condenser terminals during a complete cycle of the test, that is during the charge, the standing, the discharge, and the recovery periods. Such data would be very helpful in explaining the apparent saturation of the dielectric previously referred to. It would also give a better idea as to the behavior of the contacts and the effectiveness of the discharge circuit in removing basic quantity of electricity on the basic charge.

W. B. Kouwenhoven: The device developed by Mr. Marbury possesses many valuable features. It is similar in certain respects to the apparatus developed by the Bureau of Standards for charging and discharging condensers by the method of mixtures.[4] All, who have used this apparatus, know that different results will be obtained when the time of the charge, mix and discharge cycle is varied in any manner.

Mr. Marbury in his paper mentions the operation of his device at only one speed. It would be valuable to know what results would be obtained with some other cycle of charge and discharge and perhaps it would be possible to find some speed which will give results that would indicate more definitely the relative values of different types of insulating materials.

W. A. Del Mar (communicated after adjournment): A century and a half ago, Franklin made a Leyden Jar with removable coatings and found that the charge adhered to the glass and not to the coatings. Until three years ago this experiment was regarded as proof that the electric charge was held by the dielectric. In 1922, however, Addenbrooke upset this theory by repeating Franklin's experiment but taking special precautions to keep the surfaces of the glass absolutely dry, when he found that the charge adhered completely to the metal coatings. (*Phil. Mag.* 1922, Vol. 3, pp. 489 to 493). In Franklin's experiments, the charge which appeared to be in the glass was really bound to the moisture films on the surface of the glass.

There is moisture within most insulation and it can hold charges when the coatings are discharged. They would dissipate slowly through the high resistance of the dielectric, giving rise to residual-charge effects. It is therefore not necessary to assume the movement of moisture to explain dielectric absorption. The moisture merely acts as secondary or internal electrodes.

Mr. DuBois explains the effect of moisture by assuming that it collects in threads, stretching between electrodes, absorption being due both to the mechanical energy required to build the threads and to their influence in promoting the Clerk-Maxwell effect by shunting parts of the dielectric. If this were correct, the presence of moisture in sufficient quantities to produce distinct absorption effects, should materially lower the breakdown voltage due to the short circuiting of parts of the insulation by these moisture filaments. This, however, is not the case, as tests with manila-rope paper, impregnated with petrolatum, show a distinctly higher dielectric strength when the paper is not dried prior to impregnation than when it is dried.

Research work is now needed to determine definitely whether the Clerk-Maxwell effect holds quantitatively in the absence of moisture and whether the added effect of moisture can be explained quantitatively by internal charges. If not, it will be time to look into the more complex theories that have been suggested.

E. S. Lee (by letter): The methods of measurement of residual voltage are of long-time standing. The particular feature ascribed to Mr. Marbury's instrument is that readings are obtained at intervals of 0.1 sec. up to 1.1 sec. after the condenser has been discharged. The means adopted for doing this excludes the usual caution that the condenser must be entirely discharged so that no residual charge remains for succeeding voltage applications. For this reason it would appear that results obtained by the instrument described by Mr. Marbury would be a function of the instrument constants.

Although not specifically stated, it would appear that the curves in Figs. 8 and 9 are obtained on comparable condensers. On the basis of this assumption it is interesting to note that the residual-voltage characteristics of an untreated-paper condenser during the drying (Fig. 8) are practically identical with the residual-voltage characteristics of treated-paper condensers having values of power factor from 0.2 per cent to 0.5 per cent (Fig. 9). From a standpoint of voltage rating and effectiveness of operation, the untreated-paper condensers would in no wise compare with the treated-paper condensers. The similarity of residual-voltage characteristics for such dissimilar insulations indicates the limitedness of the residual-voltage curves as a criterion for the effectiveness of insulation.

While claims are made by Mr. Marbury that all tests to date indicate that the residual-voltage curves are of the greatest value, it is interesting to note that while nothing new is pointed out by the author resulting from these curves, there is a correlation made between these curves and the values of power factor of the condensers measured. It would appear, therefore, that the correlation between the residual-voltage curves and the life of the insulation is not different from what we now know as between power factor and life.

R. E. Marbury: There are of course many causes of insulation losses, such as conduction losses, losses in the metal plates, and the so called hysteresis loss. The magnitude of the various losses depends a great deal on operating conditions, for example on extremely high frequency the $I^2 R$ losses in the metal plates might be of great importance. On commercial frequencies such as 60 cycles the hysteresis type of loss is of greater importance, since the other losses can be reduced to neglible figures very easily. There is every indication that at least the most important cause of this hysteresis effect is absorption.

The long-transient residual curves have been observed for

2. A New Method for the Testing of A-C. High-Voltage Paper-Insulated Cables. A. I. E. E. JOURNAL, Vol. XLII, March 1923, p. 247.
3. Abridged A. I. E. E. JOURNAL, Vol. XLIV, February 1925, p. 156.
4. Curtis, H. L. *Bull. Bur. Stds.*, Vol. 6, p. 441, 1911.

many years. It is quite common to receive a severe shock from a condenser after repeated attempts to discharge it. Maxwell's theory of absorption explained these long transients very well, and many investigators have plotted the residual voltage against time over long periods such as minutes, hours or even days after discharge. It can be easily shown mathematically that a condenser will develop these residual voltages if the products $R\,C$ for the various layers of insulation are not constant.

It has been recognized for a long time that the residual phenomenon of this type could not account for 60-cycle losses, due to the short duration of charge on 60 cycles, and that if 60-cycle loss was to be explained on this basis the same form of phenomenon would have to occur at a high rate of speed. The latter would require some very low products $R\,C$ as compared with the values capable of producing the common type of residual curves. In view of this, other more complicated theories of absorption were conceived, most of them admitting an actual lag in polarization. It is quite possible that there is a lag of this type but on 60 cycles it must be so slight as to be beyond measurement, and relatively unimportant from the point of view of losses.

While the model condenser may be only a rough approximation of a real condenser it may be used to a good advantage in discussing the phenomenon. Maxwell's theory is very useful. A model condenser such as shown in Fig. 4 of the paper will give a residual curve as shown in Fig. 5. If the values R_1 and R_2 are increased the time required for the residual to reach its maximum value increases. The time required for the model to reach its steady state on charging also increases. The values R_1 and R_2 may be varied over unlimited range but the nature of the residual curves will be always the same. If we use an actual condenser, which in reality is composed of many such models in parallel, and charge it for a long time we will obtain a residual curve which may require hours to build up to its maximum value. If we repeat this using shorter and shorter charging time we will find that as the time of charging is reduced the residual reaches its maximum value sooner. As long as we can continue reducing the charging time and obtain the same form of residual curves we are apparently correct in assuming that the cause of the residual is the same. Since the condenser is composed of many values $R_1\,C_1$, or $R_2\,C_2$, and since it is easily shown that the smaller these products the more rapid is the residual transient, it naturally follows that as the charging time is reduced the lower products $R\,C$ participate the most in producing the residual curves. The same may be said for long charging intervals until the charging time is long enough for the steady state to be reached for the largest products $R\,C$. If the charging time is augmented beyond this point the residual curve will not be affected.

The dielectric lag meter was developed to measure the residual curves with very short charging periods. The work that has been done has shown that the residual curves thus obtained are of the same type as with longer charging, thus proving that there are in a dielectric products $R\,C$ which are low enough to explain 60-cycle losses, and that the only difference between these residual curves and those heretofore obtained is that they build up very quickly, as is to be expected.

The principle of Maxwell's theory need not be modified. However, certain secondary phenomena do exist. The resistivity does not remain constant with voltage apparently due to movement of moisture under the influence of the field. Furthermore, the lines of force are not always perpendicular to the various materials, or to the metal electrodes, but become refracted in passing through media having different specific inductive capacities.

Dr. Whitehead spoke of the inability of the lag meter to record the entire or true residual curve. If Dr. Whitehead considers the true residual curve as that which would be obtained if the condenser remained on charge until a steady state is reached, then the lag meter will not measure it. Such a residual would require hours to develop, and the charging time would be of the same order. As stated above the special object in view in the design of this device was to measure the residual that may be secured with very short charging periods, or where the residual obtained is a function of low products $R\,C$.

In the paper the charging period mentioned in several illustrations is 1/10 sec. It was not intended that this figure be considered as important, as the charging time may be varied over a wide range during any investigation. The duration of discharge may also be varied depending on the data desired.

Dr. Whitehead mentions the effect of previous charge on residual curves, or in other words the "past history" of the dielectric. It is a fact, as can be readily shown, that if a dielectric is subjected to a routine charge and discharge a cyclic condition is quickly reached where the residual curves will repeat themselves very accurately for each charge and discharge, and the effect of previous charge disappears. With the lag meter this cyclic condition is reached long before the first reading can be taken, and in any case the galvanometer could not be balanced until this condition existed.

A graphic check on the results that may be obtained, in so far as accuracy is concerned may be shown as follows:

Take the case of a model condenser such as shown in Fig. 4, but having the following values.

$C_1 = 1.89$ microfarads $\quad C_2 = 3.11$ microfarads
$R_1 = 796{,}000$ ohms $\quad R_2 = 4000$ ohms.

It would be desirable to use for C_1 and C_2 perfect condensers, that is condensers having no residual of their own, otherwise the formula would not hold perfectly. The condensers used were not perfect but had a residual which was small compared to the residual caused by the model.

If we charge this condenser for a time T at a voltage V_o the voltage being applied instantaneously, and then discharge it through an infinitely small resistance, the connection being left for an infinitely short time, we find mathematically that the residual voltage V at any time t after discharge follows the formula

$$V = V_o \; \frac{R_1\,C_1 - R_2\,C_2}{(C_1 + C_2)\,(R_1 + R_2)} \left[1 - e^{-\frac{T}{(C_1 \times C_2)} \times \frac{R_1 + R_2}{R_1\,R_2}} \right] \left[e^{-\frac{t}{(R_1\,c_1)}} - e^{-\frac{t}{R_2\,c_2}} \right]$$

Calculating the residual on the above basis and using 100 volts for V_o and 0.07 sec. for T we obtain the dotted curve shown herewith in Fig. 3.

The solid curve in Fig. 3 was made on the same model using the lag meter but with a discharge resistance of 10 ohms left on for 0.0003 sec. If the two condensers C_1 and C_2 had been ideal condensers the curves would have practically checked.

Mr. DuBois states that the moisture films are elongated by the field sufficiently to bridge a part of the dielectric. He states that the current probably disrupts these paths and causes the unproportionality of residual to applied voltage.

It might be added that while this phenomenon may exist under certain conditions there is a movement of moisture that takes place very quickly. Probably the moisture movement that causes the shape of curve Fig. 10 in the paper is of a different nature from that Mr. DuBois has in mind. To illustrate this Fig. 4 is given herewith. This shows five residual curves made on the same condenser but with different charging times from 0.0014 sec. to 0.07 sec. When the charging time in this particular case exceeded 0.0035 sec. the curve took on a saturating shape. This became quite marked at a time of charging of 0.0065 sec., and the curve became almost horizontal with a charging time of 0.07 sec. This shows that a certain time is required for the moisture movement to take place. It is even more interesting to note that Curves A, B, C, D, E, may be made in any order and the same curves obtained, or any one curve may be made with increasing or decreasing voltage. This shows the wonderful accuracy of movement of the moisture, and suggests

a movement within the limit of the surface-tension restoring force, rather than an extensive elongation and volatization as suggested by Mr. DuBois. If the condition exists as described by Mr. DuBois it would probably not repeat itself so accurately.

In reply to Mr. Davidson, residual-voltage curves as shown in Fig. 10 of the paper are made as follows. As far as balancing is concerned the lag meter is operated in the same way as when taking a residual curve as it builds up with time. The time-setting switch is left on one point and the residual thus obtained for this given time after discharge is plotted against applied

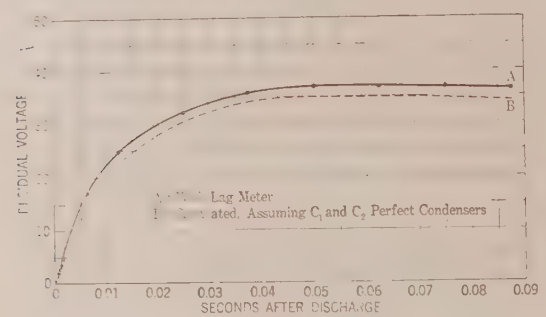


Fig. 3

voltage. Another way of course would be to run complete residual curves as in Fig. 9 for different applied voltages, then take the residual values corresponding to any desired time and replot against applied voltage. The same curve would be obtained of course in either case. The applied voltage was varied by means of a three-point rheostat having such characteristics as not to affect the results. If there were an effect of this kind the straight line as in Fig. 6 could not be obtained, neither would the straight lines as in Fig. 4 herewith be possible.

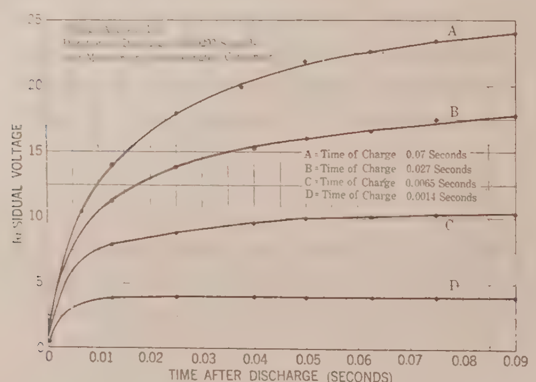


Fig. 4

Mr. Davidson mentioned the difficulties experienced in attempting to test cables by the charge-and-recovery scheme, owing to the large amount of energy handled. With the lag meter it is possible to read residual voltages as low as 0.1 volt with accuracy. There is no need therefore, to use more than 100 volts. The lag meter works very satisfactorily on condensers having capacities as high as 10 microfarads. By slight adjustments it works equally as well on 100 microfarads.

Mr. Davidson asked how one could be sure that the discharge resistance was of the proper value, or if the discharge time was correct. This paper was written to describe the principle of measurement rather than the actual details and physical nature of absorption. It is possible that we may later have some thoughts to offer on the subject of absorption in the light of data being obtained. Shortly after the contact drum described in the paper was made, a new drum was made which made possible a wide range of variation of time of charge, discharge, and the values of time following discharge were made smaller. This new drum was arranged so that the first point on the residual curve was only about 0.00035 sec. after discharge. This made it possible to observe at once if the condenser was discharged to practically zero.

In reply to Mr. Kouwenhoven regarding the speed, the speed may be changed at will by changing the worm-gear ratio on the driving mechanism. The speed which has been found of greatest value is such as to permit a charging time of 0.0025 to 0.07 sec.

Mr. Delmar refers to some of the more complicated theories of absorption many of which assume an actual lag in polarization.

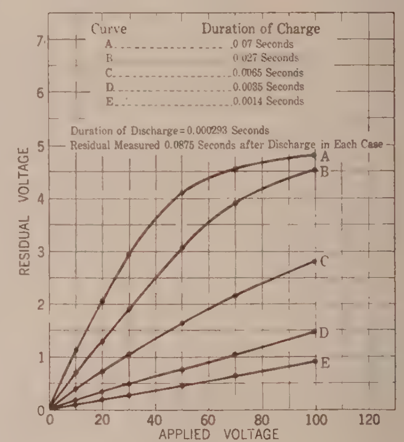


Fig. 5

Maxwell's theory will hold wherever the product $R\,C$ is not the same throughout the entire mass of material. We have only to show that in a dielectric there are products $R\,C$, low enough to cause, or explain 60-cycle losses. The lag meter has proven the existence of low products $R\,C$, by the fact that with it, it is possible to record residual curves which build up to their maximum value in short spaces of time. Fig. 5 herewith gives a few such curves which show definitely the existence of such a condition.

Mr. Lee has called attention to the comparison between curves Fig. 8 and Fig. 9, stating that the residual is as high on the impregnated condenser as before. The statement that a condenser having power losses of the order of 0.5 per cent has higher residuals as shown by curve No. 5 Fig. 8 is incorrect. It should read Fig. 9. No comparison can be drawn directly between Figs. 8 and 9, as far as values of residual are concerned Curves 1, 2, 3, 4 and 5 of Fig. 9 bear a relation to 60-cycle losses.

Discussion of Technical Committee Reports

PRESENT STATE OF TRANSMISSION AND DISTRIBUTION DEVELOPMENTS[1]

(Thomas)

Saratoga Springs, N. Y., June 23, 1925

P. H. Chase: In discussing the "Present State of Transmission and Distribution Developments," I wish to mention some of the problems which are confronting engineers in the establishing of a-c. distribution networks.

The problem of supplying service of the utmost reliability to important load areas resolves itself into the following elements:

a. Number of substations and generating stations supplying the network.

b. Arrangement and protection of primary feeders and transformers supplying the network.

1. A. I. E. E. Journal, Vol. XLIV, October, 1925, p. 1082.

c. Protection of mains in the secondary network.

The first element is usually determined by the particular system and district under consideration, though, obviously, the larger the number of substations or stations supplying the network, the greater the reliability of service.

The arrangement and protection of the primary feeders and transformers are probably the most important elements in the problem. Although there are many schemes under discussion and on trial, they all reduce practically to a few main groups. The feeder arrangements may be classified as "loop" and "radial" and the protection as "primary" and "secondary."

For maximum service continuity there must be an interlacing of different feeders, and this may take several forms in both the radial and the loop schemes. The degree and kind of interlacing affect the capacity of feeders and transformers and the operating characteristics of the system.

In general, the radial-feeder scheme involves the use of a secondary circuit breaker, which opens under reverse power and may be reclosed either automatically or by hand. It is usually backed by fuses. The automatic reclosing breaker, after tripping under reverse power from the network, will reclose in case the voltage on the network side is lower than on the transformer side. The feeder and all its transformers are disconnected from the system in the event of any fault.

The loop-feeder scheme has feeder-sectionalizing breakers on the primary side and can be operated with an automatic breaker or only fuses on the low-tension side of the transformers. As the loop is sectionalized, in the event of trouble, only a section of the feeder is disconnected from the system. In view of its simplicity and reliable operation, the balance pilot-wire protection method appears to be preferable to the reverse-power method on loop feeders.

The transformers may be isolated separately from the feeder sections or may be solidly connected to them and operate as a unit with them. Differential protection can be employed across each transformer bank, with either the radial or loop scheme.

There is also a question as to the proper reactance of transformers for networks. This is affected by main size and length, transformer capacity, characteristics of loads, configuration of streets, etc.

The protection of the secondary network system, usually considered in the form of a gridiron, is divided into two schools; one, based upon faults in the mains clearing themselves by burning off and the other, based upon fusing the mains to disconnect the main in trouble. Further investigation of the action of arcs, values of short-circuit currents, etc., on mains of networks with different types of cable, and further knowledge of the characteristics of fuses are needed.

For the purpose of arriving at quantitative solutions of many of these conditions, there is being made a single-phase, a-c. calculating table upon which can be set up practically any combination of substations, feeder arrangements, transformer sizes and reactance and secondary loads at different power factors. It is hoped that this table will accurately answer a number of these questions with minimum consumption of time.

Although the last year or two has been productive of a great deal of investigation and discussion, much more engineering study should be devoted to this problem in order to establish a solution satisfactory from the points of view of service continuity, operating convenience and economy.

F. W. Peek: There are two phases of the subject of power transmission which I wish to discuss.

I will first consider the cause of failure of insulation and the failure and arc-over of line insulators.

Insulator failures or arc-overs may be caused either by voltages in excess of the arc-over voltage or by mechanical deterioration or dirt so reducing the insulation that breakdown occurs at normal voltage, or by a combination of the two.

The *over-voltages* that can occur on transmission are due to lightning or to internal surges due to switching or arcs. All such over-voltages are either impulses of steep wave front or highly damped oscillations. The insulator arc-over for such transient voltages is always higher than for 60-cycle voltages. On modern systems and especially on grounded-neutral systems very little need be feared from internal surges.

This leaves the main cause of present failures to be either excessive lightning voltages or mechanical trouble and dirt. I am simply summarizing here the position that I have maintained for years.

Lightning arc-overs will occur on any system when the insulator lightning arc-over voltage or the lightning arc-over voltage from conductor to tower is less than the lightning voltage to which the system is subjected. I have recently read papers by operators and transmission-line designers where hope was expressed for a lightning-proof insulator. This rests to a greater extent with the tower designer since as long as the insulators and lines are immersed in air the lightning arc-over voltage will be determined almost wholly by the length of string and tower clearance that the tower designer feels it is economical to allow. This is fundamental.

An example may be of interest. I have shown that the maximum lightning voltage that can occur on any line is equal to the average height of the transmission line in feet multiplied by 100,000. The chance of this maximum condition occurring is generally quite small. Assume a 30-ft. line: The maximum lightning voltage is $30 \times 100{,}000 = 3{,}000{,}000$. A 14-unit insulator string has a lightning arc-over voltage of 1,700,000. A 14-unit string on such a tower must, therefore, flash over if the severest lightning storm, practically a direct stroke, occurs over the line. It may be that this would be so infrequent that more insulators or greater tower clearances would not be warranted. If a ground wire could be installed with good grounds, the maximum lightning voltage would be 1,500,000. The 14-unit line would then be lightning-proof. I am giving this example to show that the question is subject to calculation as are other engineering problems.

Since it may not be economical to make most lines absolutely lightning-proof it becomes important to take care of these infrequent troubles with the least possible disturbance. This can be done by providing a grading and arcing ring and quick sectionalizing relays. The object of the grading ring is to make operating and lightning voltages divide evenly over the string, to cause greater voltage stability, to prevent corona and to make any occasional arc-over clear the string and prevent damage to the string and conductors. However, no such device can take the place of string length or tower clearance.

The effect of dirt, as well as the cure for a certain type of dirt, is well illustrated by the experiences of the Southern California Edison Company. The importance of the grading and arcing ring also showed its value here.

I wish now to say a few words regarding corona:

The question of corona loss does not and need not offer serious difficulties for high-voltage transmission. Even at 220 kv., economical transmission generally necessitates such a large block of power that the size of the conductor is fixed above the corona requirements by $I^2\ R$ considerations. If this is not the case, the size can generally be increased inexpensively by means of a core or otherwise. There is thus no need for appreciable corona loss on a 220-kv. line.

The diameter has the greatest effect on the critical voltage. However, the roughness of the surface measured by the "irregularity factor," is an important factor and care should be taken when special conductors are used that the diameter is not increased at the expense of surface regularity or there may be no gain. Care should be taken in installing conductors that the surface is not mutilated. Such mutilation decreases the "irregularity factor" and increases the loss above the calculated loss near the critical voltage. While such irregularities may "oxidize" away in time they are highly undesirable.

The visual critical corona voltage can be calculated with great accuracy for a smooth conductor over a wide range of conditions of temperature and barometric pressure. In fact, this law is so exact that it offers a means of measuring voltage. With irregular conductors, the irregularity factor must be known and the starting voltage is less sharp as local corona appears on the sharper irregularities before complete corona.

The quadratic law for calculating the loss gives quite accurate results above the visual voltage and offers a means of closely approximating the loss below this voltage for conductors that have not been mutilated and where the irregularity factor is known. There is sometimes difficulty in estimating the loss with very great accuracy near the e_0 voltage in new lines and new conductors because there is no way of knowing the roughness caused by installation. This roughness will, in fact, vary with the conditions along the line.

Measurements show that for *new concentric-lay cables* about 1 in. in diameter the irregularity factor is approximately the same for 19, 37 and 61 strands and varies from 0.80 to 0.85. In special conductors it may be lower. A seven-strand cable of large size is not good because the strands are likely to become mutilated. The irregularity factor generally improves as the cable is used, due to weathering and the action of the corona brushes in reducing the irregularities. An aluminum cable of slightly less than an inch in diameter and several years in operation has an irregularity factor of 0.85 to 0.89, while a similar cable newly installed had a much lower factor. A figure between 0.88 and 0.89 should be possible in practise.

In general, as already pointed out, it is desirable to operate below the e_0 voltage where there is no appreciable corona loss. This should offer no difficulty, even at 220 kv. since, if the conductor is not large enough from other considerations, the diameter can be increased by a core.

J. B. Whitehead: In connection with the comments of Mr. Peek I wish to say just a word on the subject of corona as a protective measure on high-voltage lines.

I gather from Mr. Peek that he does not consider that corona is a particularly promising method for this purpose. At any rate, he suggests that it is more than advisable not to allow corona to arise on the line. The obvious objection to the presence of corona in any considerable amount is the loss of power occasioned thereby. But there can be no great objection to having a moderate amount of corona present, particularly if this is confined to a short section of the line. The power loss occasioned thereby can be reduced to entirely negligible proportions.

It is only necessary to have quite limited sections of the line—a mile or two—discharging with corona in order to obtain most of the benefits of corona as a protective measure.

It is well understood that for any type of line shunted conductance has the effect of reducing both the steepness of the wave front and also the amplitude of any high-voltage disturbance that advances along it. Rigid analysis shows this beyond all question.

It is possible to operate a relatively short length of line with a moderate amount of corona upon it; the loss of power thereby would be next to nothing, yet it is possible to reduce the steepness of the wave front and also the amplitude of these high-voltage disturbances before they reach the station. I do not suggest that this method could be used for the protection of all the insulators without great complication and possible expense; however, as regards the protection of the ends of the line, there seems to be considerable promise for it.

A number of definite statements have been made by the operating engineers of some of the high-voltage lines in California, that they have good reason to believe that much of the stability and freedom from high-voltage disturbances is due to the fact that a considerable portion of their lines were being operated with a moderate corona loss.

Certain experiments have been made[2] directed toward the steepness of the wave front and the amplitude of high-voltage transients disturbances, and these showed beyond question that these waves were attenuated and their amplitude was reduced.

E. S. Healy (by letter): Very high-strength conductors with long spans offer an economical type of construction for high-voltage lines, especially where heavy ice loads are encountered. Savings in cost resulting from any particular type of design cannot, however, be expected to assume very large proportions of the total.

How far the idea of long spans and high strength can be economically carried depends on the general scheme of the design. The lowest cost will be obtained by providing a conductor with such a margin of strength that, even under the maximum loads that can be expected to occur, there will be no danger of the mechanical failure of the conductor itself. This will require the standard line towers to be designed for only moderate longitudinal loads. On this basis it will be found that within practical limits the cost of the supporting structures, that is towers, footings and insulators, will be less the greater the span and the higher the conductor strength.

In considering the relative reliability of such a line, the experience with heavy wood-pole construction is very reassuring. Long lines with rather large conductor and comparatively long spans have given excellent service, even though these structures are entirely incapable of withstanding the maximum assumed conductor tension. Failure due to burning of the conductor is a hazard but should be rare and certainly extremely unusual under maximum mechanical load. Clearances and insulators should be designed to reduce flashovers to an absolute minimum. The insulators should be provided with rings and horns or other devices to keep the arc off the conductor.

Extra long span construction does not appear particularly economical under the usual basis of design. The usual design assumes the conductor to be the weak link. This design is not entirely logical, even though the line towers on this basis would prove very heavy and costly. The tower is generally designed to carry one or more broken conductors under the maximum assumed loading conditions. There is, however, a considerable margin between the stress in the conductor under maximum assumed load and the stress under which the conductor would actually fail, and it is not entirely reasonable to assume that a tower designed under the above assumptions is of sufficient strength to carry a broken conductor failing under an accumulation of ice and wind.

Under the very great tensions proposed, it is rather difficult to provide a suspension clamp and insulator string that would hold in case of a break. As a matter of fact it has been quite generally found that a break in comparatively light conductor under light loads will cause a slip through the suspension clamps now in general use. This idea of allowing the conductor to slip through the clamp in case of a break has been taken advantage of in some recent designs to provide a safety device on towers designed for these rather light longitudinal loads.

It is, of course, absolutely essential that dead-end angle structures be of sufficient strength to carry the conductor under practically any conditions. Such a high-strength conductor might easily become a menace under some unusual loading with angle structures designed for something less than the maximum possible loads.

Long span construction especially combined with long strings of suspension insulators introduce several new and important problems. Unbalanced conductor tensions caused by unequal spans under heavy ice loads and unbalanced ice loads require a longitudinal strength not provided by any of the usual "flexible" towers. Any type of flexible construction would be justified only after very careful study.

2. The Corona as Lightning Arrester, by J. B. Whitehead, A. I. E. E. JOURNAL, October, 1925, page 914.

The exaggerated effect of "sleet jump" on long spans will probably eliminate any even approximately vertical arrangement of conductors on extra long span lines. Experience seems to indicate that with a reasonable conductor spacing the whipping of conductors in the wind is a freak condition not peculiar to long spans. Vibration and the failure of conductors by "fatigue," though necessarily inherent in long-span construction is a very real problem on which careful observations, test, and a correct theory are all wanting.

R. W. Atkinson (by letter): A discussion of load that may be carried at various voltages needs to be prefaced by a statement of the range of available voltages. Up to the present time, the highest voltage at which cables have been operated in commercial service anywhere in the world is 66 kv., this being in single-conductor form. The company with which the writer is associated has furnished one whole line about 9 mi. long amounting to about 27 mi. of 66-kv. cable and this has been in service for well over a year without a single cable failure of any kind. Combining this operating history with further development work in manufacturing and testing, we believe that 66-kv. cable may reasonably be put in practically the same class in regard to reliability as three-conductor cables for more standard voltages. In regard to high voltages there is absolutely no operating experience. There has been a limited amount of experimental operation in this country and in Europe. One commercial installation and one experimental installation are now being planned in this country, the latter to materialize in the immediate future. Voltages beyond 66 to 75 kv. thus cannot be considered as a commercial proposition although the great demand for such operation and encouraging experimental results which have been obtained justify the hope that voltages well beyond 66 kv. and up to 132 kv. may in the future become commercial. It should be borne in mind, however, that a certain period of time of successful operation must pass before conclusions can be drawn.

With this preface, a more specific reply may be made to the topic. A 66-kv. single-conductor cable line, with two circuits per duct bank, with 750,000-cir. mil. conductors can carry in the neighborhood of a total of about 80,000 kv-a. at 100 per cent load factor without exceeding a temperature of 60 deg. cent. based on normal soil temperature and thermal constants. Not much larger conductors than this can be used to advantage without going to the complication required to prevent or reduce induced sheath losses. Peak loads larger than this can be carried in some cases depending upon thermal characteristics of the system and upon the load factor.

When 132-kv. cable has been proved to be a commercial practicability, then a capacity in the neighborhood of 60,000 to 70,000 kv-a. at 100 per cent load factor may be expected in a single circuit of 750,000-cir. mil. conductors and at a final temperature of 60 deg. cent. It probably would not be economical to operate more than one circuit in a duct line on account of the marked reduction in carrying capacity per circuit resulting from the accumulation of heating due to conductor and dielectric losses and it is likely that in most cases it would be materially cheaper per kv-a. to build two separate conduit lines if two circuits are needed.

Referring now to three-conductor cables, one 35-kv. cable would carry about 16,000 kv-a. with 500,000-cir. mil. conductors at 60 deg. cent. The capacity per cable would be reduced, especially with high load factor, if four cables are used in the same bank which is the usual practise. With six such cables in the conduit line, each could carry at 100 per cent load factor about 11,000 kv-a.

These specific figures are given for the specific purpose outlined in the question and it is important to bear in mind the possibility of very large reduction of carrying capacity due to such local conditions as heat from other sources, or on the other hand that the peak load may be materially more than the continuous capacity. Especially, is the reduction of carrying capacity due to the proximity of a number of cables greatly diminished where the load factor is low.

The question of what may be expected from high-voltage cables in the future leads directly to what has happened with cables in the past. It is my impression from the available data that such American and European cable troubles as have occurred have been principally confined to pioneering ventures departing too far from conservative practise. There have been no fundamental troubles with cable-making practise either here or abroad and as far as can be foreseen there should be none in cable-using experience as long as the principles which have been responsible for attained successes in the fields of both manufacture and service are followed or not too lightly abandoned.

D. W. Roper (by letter): Several of the larger companies are cooperating with the cable manufacturers in the development of suitable tests on cable, to be made at the factory, in order to determine its operating characteristics before installation. By means of a careful analysis of cable failures and a comparison with test results, it is hoped that it will be possible to determine what particular characteristics in the cable have caused the cable failures, and in this manner, indicate the changes that should be made in the design of the cable in order to eliminate such failures.

During the year, an installation of 44-kv. single-conductor cable has been made at Columbus; a single-conductor cable for operation at 66 kv. will be installed at Philadelphia during the year.

The tendency toward higher voltages is indicated by a trial installation of single-conductor cable operating at 110 kv. in this country, and another installation somewhat larger, of single-conductor cable operating at 130-kv. in Italy. Both of these installations have been fully described in the technical press.

In connection with the development of their plans for transmission lines forming a part of the local superpower systems, two of the larger companies are proceeding on the assumption that single-conductor cable for operation at 132 kv., three-phase, will be available within a few years.

The Committee is continuing its cooperation with similar committees of the National Electric Light Association and the Association of Edison Illuminating Companies in supervision of research into the properties of impregnated paper insulation, as follows:

Massachusetts Institute of Technology—The effect of heat on impregnated paper insulation, to be followed by investigations of the effect of heat and dielectric stresses in combination.

The Harvard Engineering School—Dielectric loss and ionization.

The Johns Hopkins University—Ionization.

University of Wisconsin—Thermal resistivity of impregnated paper insulation.

T. A. E. Belt: In most transmission lines the reactance drop is the chief voltage drop and as pointed out by Mr. Thomas, it may be compensated for by installing synchronous condensers at the end of the line. Shunt synchronous condensers, however, do not neutralize the reactance of the line but rather take a leading current which neutralizes the lagging current taken by inductive apparatus.

If a condenser of the static type or "capacitor" is installed in series with a line, the reactance of the line may be neutralized thereby leaving only the effect of resistance in the circuit.

A single-phase diagram as shown here in Fig. 1 more clearly illustrates the proposed circuit.

The transformer feeds a transmission line having reactance X_L and Resistance R. A condenser having capacitance X_c is placed in series with the line so that

$$X_c = X$$

or

$$\frac{1}{2\,\pi\,f\,C} = 2\,\pi\,f\,L$$

When this condition exists the circuit is tuned for the frequency of the system.

The vector diagram illustrates what takes place in the circuit. E_r represents in magnitude and phase the receiver voltage; ϕ represents the angle of lag of the load current; $I\ X_c$ the magnitude and phase of the drop across the series capacitor; $I\ R$ the magnitude and phase of the line resistance drop; $I\ X_L$ the magnitude and phase of the line reactance drop. Then the line $O\ E_g$ represents the magnitude and phase of the generator voltage. In other words if the reactance of the line is exactly neutralized there is left only the resistance drop.

Such a system of neutralization may have merit for long lines as well as for short lines.

P. H. Thomas: I should like to say, supplementing what Mr. Peek has said about flashover of insulators, that a little caution should be observed in making the insulator string of too high an insulation strength. If the line is so well insulated that a discharge from lightning will not go over insulator to ground, it is likely to go to the station. I think it would be much better to deal with it on the line than in the station.

I should also like to emphasize the precaution Mr. Peek used in saying that the highest voltage that might be expected from lightning in the induced voltage on the line was 100,000 times the height of the tower. That 100,000 factor is a very unusual case and I believe that the chance that this voltage would be realized in any one place is even less than Mr. Peek assumed. There is no subject in which it is more necessary to use common sense and a sense of proportion than in spending money to avoid lightning trouble.

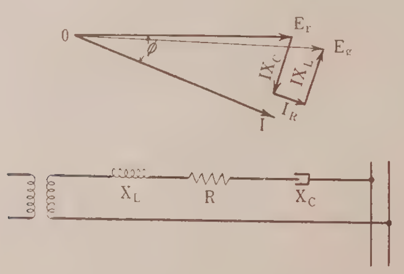


FIG. 1—SERIES CONDENSER USED TO OVERCOME LINE RESISTANCE

The diagram of Mr. Belt is very ingenious and covers a very fundamental principle, and theoretically, the result would be as Mr. Belt has given it. There are two or three difficulties in using the system of this diagram. If it were drawn a little more clearly in proportion, we would probably find that the potential existing between ground and the point of the line just before the capacitor is reached might be something like 50 per cent higher in a very long line than the 220-kv. line voltage at the end, which would be a pretty serious matter. If you picture this in your mind, we have the current going through the line with a certain drop in resistance in phase with the current and an out-of-phase voltage due to inductance which in a very long line may be almost as much as the useful voltage and also a voltage due to the capacitor in quadrature with the main voltage equal and opposite to the inductance voltage. That is to say, we have added to the other voltages due to the current a certain voltage to correct the phase. The synchronous condenser which is usually added at the end is another method of adding this same voltage in substantially the same phase relation and I think the synchronous condenser will turn out to be a much cheaper way of producing that voltage, and certainly a method very much more easily controlled and adaptable, and a method which deals with low voltages.

T. A. E. Belt (communicated after adjournment): In his closing discussion of the Transmission Committee's report, Mr. Thomas referred to the suggested method for neutraliziug a transmission line by a series capacitor. In substance his statements were:

a. If the vector diagram were drawn to scale, the voltage at the end of the line would probably be 50 per cent higher than at the generator end.

b. A synchronous condenser is cheaper per kv-a. than a capacitor and, therefore, it would probably be cheaper to install synchronous condensers in shunt at the end of the line.

c. A synchronous condenser is easier to control than a series-connected capacitor.

I wish to discuss these points.

In making the study of this circuit it was recognized that under normal conditions the voltage at no point on the line should be higher than the normal rated voltage of the circuit. Using this as a basis for calculation and neglecting resistance, it was found that the maximum load which could be carried occurred at 0.707 power factor lagging current when the capacitor was at the end of the line. Assuming that the power which can be put over the line is 100 per cent at 0.707 power factor, the values of kw. expressed in per cent for various power factors lagging current are as follows:

Power Factor	Per cent Kw.
0.5	87
0.707	100
0.8	95
0.9	79

For a 250-mi., 60-cycle, 220-kv. line, 100 per cent power corresponds to 241,000 kw.

The economics of a series capacitor installation depend a great deal upon the per cent reactance of the circuit to be neutralized. For a 30-per cent reactance, 40-per cent kv-a. in series capacitors is required to neutralize fully the reactance of the circuit. For synchronous condensers placed at the end of the line, a total of 69-per cent kv-a. is required to make the receiver voltage equal to the generator voltage, neglecting the effect of resistance. Assuming the cost of synchronous machines to be 50 per cent that of series capacitors, it is seen that for this case the capacitor installation is cheaper than the synchronous installation. For a 100-per cent reactance circuit the same kv-a. in series capacitors is required as for synchronous machines.

A series-capacitor installation requires only protection against over-voltage and no manual or automatic control is required. This is readily seen when it is recognized that the capacitor neutralizes reactance and the voltage drop across the capacitor for any load or power factor is always equal to and opposite in phase to the reactive drop of the circuit. On the other hand a shunt synchronous condenser requires field control for various loads and power-factor conditions.

P. H. Thomas: Mr. Belt has contributed some interesting discussion by letter on the use of a series condenser or capacitor to benefit long-distance transmission. This is quite a fascinating subject and much may be said pro and con.

Perhaps a helpful conception for considering the broader aspects of the scheme, assuming the more general and more favorable case of the use of a capacitor at each end of the line, is to take each condenser as a part of the adjacent terminal apparatus, load or generator, as the case may be. Taking firstly, *steady operation conditions*, it is thus seen that the only effect these condensers can have is to change the power factor or to change the voltage at the ends of the line proper. The power-factor change can, of course, be accomplished by synchronous apparatus to the same effect. The line per se could not tell whether a series condenser or a shunt synchronous machine were used. However, the change in voltage is a different matter. In general, if the voltage of the generator and the load at the two ends are kept steady the effect of the series capacitors must be to change the line voltage up or down, with change in load conditions. If the

line voltage goes up the voltage limit is exceeded, if it goes down, the power capacity is lessened.

It is entirely possible to increase the amount of power that can be transmitted over the transmission line by the use of a series condenser at each end, with the voltage held constant at the *load and generator high-tension bus*, but this can be done only by raising the actual voltage on the line itself which is in fact just the effect of the condensers. Obviously the line remains a line separate and distinct and must act as such, with or without series condensers, that is, as far as steady conditions are concerned. While the condensers may correct the line conditions for the benefit of terminal conditions or the terminal conditions for the benefit of the line conditions, it cannot change the performance of the line once the line conditions are fixed.

It can hardly be said that the series condenser neutralizes the reactance of the line, it merely corrects the terminal condition to give a load power factor and voltage somewhat approximating that which would exist without the line reactance. Any considerable drop in line voltage or any line losses due to low power factor in the line as a result of the reactance still exist in the line even with the series condenser. So much for the steady conditions.

With disturbed operation and varying load and load voltage, the series condenser makes a fine showing, for the necessary correction for the line performance with such changes are largely automatically applied *pari passu* or instantaneously by the condenser. With a synchronous condenser, however, this readjustment can be made automatic only by the slow-moving voltage regulators and exciter systems. This would apparently be a very important matter. There is, however, also a most serious offset to this advantage, for the use of the series condenser precludes any control of the voltage conditions by leading current through the line reactance. With the series capacitor, a resistance drop is a real drop beyond the ability of power factor to correct it. In fact, in long heavily loaded lines, it will be found that the resistance, though small in relation to the reactance, is a very important factor in the performance of the line.

With regard to the three statements, *a*, *b*, and *c*, which Mr. Belt has accredited to me, I should like to say that I did not intend to make quite so categorical a statement as he gives, for matters of cost and control can hardly be treated in an exact sense in general discussions of principles where no definite cases are considered.

DEVELOPMENTS IN ELECTRICAL MACHINE DESIGN[1]

(Hobart)

Saratoga Springs, N. Y., June 23, 1925

E. J. Burnham: I am very much interested in the new type of frequency changer sets, viz.: The Scherbius-controlled set briefly referred to in this paper. This type of set has proven very desirable as a connecting link between two different systems, particularly where the two systems operate at different frequencies. The Scherbius type of frequency changer has one great advantage over the ordinary type of frequency changer, in that the load may be controlled at the point of inter-connection. In other words, it is not necessary that governor settings of prime movers be changed to obtain control of power interchanged.

Reference is made to two 6000-kw. sets installed in 1924, which are, without doubt, the sets installed at Rochester, by the Rochester Gas & Electric Company. I wish to call attention to the fact that two other sets were also installed during 1924, and put into operation early in 1925. These two sets were installed at the Lighthouse Hill Station of the Niagara, Lockport & Ontario Power Company. One other set is now being manufactured for the Niagara, Lockport & Ontario Power Company, which will later this year, be installed at Falconer, N. Y., tying together the Niagara, Lockport & Ontario system with one of the Pennsylvania systems.

All five of the sets mentioned tie together systems of 60-cycle and 25-cycle frequencies. They could be used also for tying together systems of the same frequency, although this does not make quite so economical a proposition.

Anyway, in tying together systems of different frequencies, frequency converters are necessary therefore, it is well worth while to use the Scherbius-controlled sets, as the increase of price of such sets is well offset by the advantages thus gained.

J. C. Parker: Mr. Burnham clearly states the essential advantage of the Scherbius type of frequency converter. It is questionable whether the use of a set for tying systems of identical frequency could justify itself and the writer does not understand Mr. Burnham to claim that in all cases the extra cost of the Scherbius set would justify itself.

There is little doubt that such a method of connection would prove particularly interesting where parallel connections are made or particularly where the parallel connections are of different characteristics.

A YEAR'S PROGRESS IN LIGHTING[2]

(Stickney)

Saratoga Springs, N. Y., June 24, 1925

C. H. Sharp: There is a development mentioned in Mr. Stickney's report which is very interesting and at the same time which might be overlooked. I refer to his mention of a practical method of realizing the reproducible primary standard of luminous intensity,—something which has been greatly needed for many years. In a paper by Dr. Herbert E. Ives, presented before the International Commission on Illumination at Geneva last summer, Dr. Ives has shown how it is possible to realize in practise a primary standard based on the brightness of a black body radiator at the melting point of platinum. The theoretical proposal of a standard on this basis is not new but was made some years ago by Waidner and Burgess. As a result of that presentation the International Commission on Illumination passed a resolution to the effect that the various national laboratories should be requested to investigate this question along these general lines with a view to proposing definitely a standard of light. It is to be hoped that this will result before many years in having a standard of light which is really fixed and reproducible from specifications.

THE ACTIVITIES IN RESEARCH[3]

(Whitehead)

Saratoga Springs, N. Y., June 23, 1925

D. W. Roper: I should like to suggest more fundamental research on the subject of high-voltage cables. During the past five or six years, the manufacturers in this country have made some wonderful improvements in their workmanship. They have increased the dielectric strength 60 percent in this period as shown by a summary of the record of three of the representative manufacturers. They have reduced the dielectric loss so that this dielectric loss, as the cable leaves the factory, is so low that failures from this cause cannot occur. But in reducing the dielectric loss, they have sacrificed the life of the insulation.

To make this statement plain, I shall say that there are records showing that cables of the old resin-oil type, combinations of resin and resin oil, have operated for fifteen years without developing any signs of deterioration or ionization, and that when cables of the same thickness of insulation but impregnated with the modern compounds of low dielectric loss, are operated at the same voltage, the life of the cable instead of being fifteen years, is, in some cases, less than fifteen months. That experience is not

1. A. I. E. E. Journal, Vol. XLIV, August, 1925, p. 902.

2. A. I. E. E. Journal, Vol. XLIV, October, 1925, p. 1116.

3. A. I. E. E. Journal, Vol. XLIV, October, 1925, p. 1082.

confined to any one operating company or the product of any one manufacturer.

During the same period of five or six years, one manufacturer admits using eight different impregnating compounds. There are other manufacturers who perhaps, may not have made quite so many changes.

When such changes occur with anything like that rapidity, it is perfectly obvious that the research by which they are determined is not of the fundamental variety.

The cable made with the various impregnating compounds is given the ordinary test, but apparently it is not given a sufficient test or the right test to determine the life of the insulation.

The high-tension cable industry is important to the central stations. It is all very well to reduce the cost of generating stations, but unless you can successfully get power away from the generating stations you are in difficulty.

The old resin-oil cables failed from dielectric loss but after we learned how to operate them and reduce their current to the proper rating, they could be operated successfully for longer periods and with a very small percentage of failures.

The trouble with the recent compounds is due to the voltage,—not to the current,—and the only way in which this loss can be reduced is by reducing the voltage, which, of course, means a serious reduction in the carrying capacity of the cables, as well as some serious changes in transformers and other equipment.

I allege that only by some fundamental research is it possible for distinct improvement to be made in the cable manufacturing art in this country without resorting to the expedient recently adopted by two American manufacturers, *i. e.*, acquiring a few leaves from the note books of foreign manufacturers.

W. A. Del Mar: Research in the cable factories has not always been along the lines of progress indicated by experience, but has often been pushed in one direction or another as enthusiasm for certain qualities waxed and waned. Thus resistivity, dielectric loss, dielectric strength, and ionization have all had their day, the last being still in the ascendency as a favorite indicator of cable quality.

In my opinion, the two most important characteristics have not yet had their day of popularity; namely, thermal resistivity and chemical permanence of the compound under electric stress.

Cables impregnated with petrolatum, either pure or mixed with resin, deteriorate under prolonged exposure to high stresses, the oil hardening into an opaque, pasty substance which is variously described as cheese, wax, etc. This substance is a mixture of oil and a flaky substance which may be designated as X until a real name can be conferred on it. The problem arose, therefore, to determine the nature of this substance and my associates are now able to report some interesting results.

The first point of interest is that X is an oxidation product of the oil. The oil becomes highly polymerized and oxidized, but it is the oxidation which is of special interest and importance to us, as it shows that this material cannot form except in the presence of oxygen and, therefore, that if a cable is completely saturated and air-free, it cannot form.

It was found that X is a product of certain constituents of the oil and oil can be compounded which contains such small proportions of the objectionable constiutents that, so far as can be determined by tests, it is stable under stress. The problem of obtaining stability under high stress has therefore probably been solved, but of course a thing like that cannot be determined absolutely definitely until after some years of trial. Accelerated aging tests, however, made at three times the working voltage, and lasting from one to two weeks, indicate that the oil is stable, whereas, in all of the older oils, complete solidification occurs.

G. B. McCabe: I wish to support Mr. Roper strongly in his stand for greater life in cables. Until the present year we have felt satisfied so far as cable performance in the 20-kv. to 33-kv. class was concerned. But suddenly it seems something has happened and so changed the manufacture that the cables which we were assured were improved products, started failing upon being placed in service. Some of the new cables recently installed by The Detroit Edison Company have failed on a kenotron or proof test equivalent to but normal a-c. operating voltage. It seems that the manufacturers, in improving dielectric strength, dielectric losses and some of the other factors, have greatly sacrificed cable life.

ELECTRICITY'S PROGRESS IN THE IRON AND STEEL INDUSTRY[1]

(CROSBY)

SARATOGA SPRINGS, N. Y., JUNE 24, 1925

H. E. Ramsey: Mr. Crosby brought out the fact that for the first time 60-cycle installations are now in excess of 25-cycle installations in the iron and steel industry. Is this altogether due to new 60-cycle installations, or is there a tendency to change over old ones from 25 to 60 cycles?

I think that the cause Mr. Crosby has assigned for this is undoubtedly the correct one; namely, that 60-cycle transmission systems are now of larger size and greater dependability, so that advantages of purchased power have overborn the inherent advantages of 25 cycles for this class of work. Those of us who have 25-cycle plants on our hands, would be glad to know what the tendency is with regard to the spending of the considerable amounts involved in changing from 25 cycles to 60 cycles.

PRECISION WATTHOUR METERS AND HIGH-FREQUENCY MEASUREMENT[2]

(KNOWLTON)

SARATOGA SPRINGS, N. Y., JUNE 23, 1925

D. W. Roper: I should like to suggest that the Committee on Instruments and Measurements give some attention to the question of measurement of dielectric loss or power factor of high-tension cables. A number of the manufacturers have several different schemes in operation, and each manufacturer claims that his particular scheme of measurement is accurate.

They test their own scheme in their own laboratory, ordinarily by testing first a long piece of cable and then cutting it in two and testing each of the halves. If the two halves test with each other and the original measurement on the entire length, then it is assumed that the measurements are accurate and that there are no losses. Accordingly, two pieces of cable taken from the same reel were sent to two different factories for measurement of dielectric loss, and according to the theories which they use in checking their own instruments, these measurements should have been alike. As a matter of fact, they varied by over 100 per cent.

If they vary among themselves by over 100 per cent in the measurements on which they are relying to determine the quality of their product, apparently some attention should be devoted to the accuracy of those measurements.

W. A. Del Mar: Mr. Roper said that, in the measurement of dielectric losses, the cable manufacturers check their measurements by testing a length of cable and then cutting it and repeating the test on the parts. This is certainly an unsatisfactory method as it does not really check anything. We have three systems of measuring power factor; one, using a wattmeter as a deflection instrument; another, using a wattmeter as a zero instrument; and a third, using a zero galvanometer. We occasionally check the methods against one another, and, if we can get consistent results, we feel reasonably satisfied that all methods are giving satisfactory measurements.

I endorse Mr. Roper's suggestion that the instrument men give some further consideration to the measurement of low power factors, especially with direct measuring instruments. The measurement of such exceedingly small power factors as are now obtained, a fraction of one per cent, with any kind of direct-reading instrument, will however, tax their ingenuity to the utmost.

1. A. I. E. E. JORNAUL, Vol. XLIV, September, 1925, p. 961.
2. A. I. E. E. JOURNAL, Vol. XLIV, September, 1925, p. 967.

WATTLESS FLUX

By Carl Hering

The acceptance of the conception of what might be called *wattless flux* will clarify the true meaning of that admittedly ambiguous term, self-inductance, about as the conception of the wattless current clarified the distinction between a true resistance, a reactance and an impedance. The basic distinction in both is real *vs.* apparent energy.

Flux is considered wattless, however, for a different reason than in the case of current. It must be considered as wattless whenever its stored energy has already been included or accounted for in a resultant of all the flux energy. When, in any system of forces, the *total* energy is deduced from the *resultant* of all the forces, it is evidently wrong to then deduce that for each of the components also and add them to it to get the total; that is adding again that which has already been added, and of course makes the total too large, even infinity (by integration) in some cases. Yet this has been done, and we have deceived ourselves, just as we did before the difference between a true resistance and a reactance was generally recognized, resulting in the wattless ampere.

In the above case, the components which had been included in the resultant must then be considered as wattless, but merely when computing the *total* energy from the resultant, as each component, when acting by itself, could generate true energy. The e. m. f. induced by cutting or linking them, being independent of the energy in them, is not affected by this wattless feature. The writer will discuss this more in detail and show how it effects self-inductance in a forthcoming paper on a broader subject.

UNITARY OPERATION OF UTILITIES WITH INTERCONNECTION

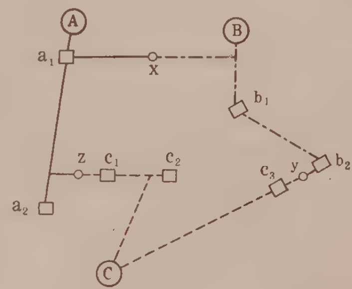
By Percy H. Thomas

When exchange of power is undertaken between adjacent utility companies, a decision must be made as to whether these companies are to be operated as independent units delivering definite, predetermined amounts of power to one another, or whether there is to be unitary operation; that is, operation with a single load dispatcher for the zone and coordinated governing of frequency. This is a matter of far reaching importance, as unitary operation calls for a large measure of operating cooperation and for some degree of common interest.

On the other hand, with unitary operation once provided for the purpose of interchanging surplus power and for automatic mutual support in time of breakdown, there is secured, at the same time, opportunity to make very material savings in the cost of producing power by loading to the full the more economical machines in the interest of the zone and also the ability to carry an increased load without increase of generating capacity on account of the very material reduction in the amount of reserve capacity required in the zone as a whole with unitary operation.

The purpose of the present discussion is to emphasize the view that when more than two or three companies are involved, interconnected at several points, unitary operation will be almost a necessity, for it is not likely to be found practicable to manipulate governors and field rheostats to simultaneously deliver several prescribed amounts of power at suitable power factors from certain designated stations to others, nor to maintain such a condition if once established. The difficulties are increased because the system frequency must at the same time, be accurately maintained.

Consider the hypothetical network illustrated, showing three company systems, interconnected at x, y, and z.



A, B and C are the generating stations and a_1, a_2, b_1, b_2 and c_1, c_2, c_3 are the substations.

Remembering that the distribution of load between stations is determined solely by the power developed by the prime movers driving the generators, it is clear that with the connection at x closed and the connections at y and z open, A can deliver power to B, through the adjustment of governors at either station, A or B, or both, and that each company can tell what power is being delivered by instruments at x. Furthermore, while the amount of power interchanged will vary with changes in load in either system, correction can be made by either company. The companies may thus maintain their independence of operation.

Suppose, now, a connection be made at z as well as x and that A undertakes to receive power from C to deliver to B. It will not now be possible to tell how much of the power taken by A at z is delivered to B, without determining the actual total load on A by summing up all the substation loads. Once the power from C is scrambled with the power of B, it cannot be unscrambled. The transmission line losses also are a definite source of error. Furthermore, if, by dint of careful cooperation, the prescribed amounts of power from C to A are delivered to B, then any change of load anywhere will upset this condition.

If the additional connection at y is then closed, no particular change of the governor adjustments is required, but the difficulty of determining how much power is being delivered to B by A and how much by C is increased. The flow in y might even be backward.

However, with unitary operation there would be no

difficulty in the delivery of the prescribed amount of power to B and in *approximately* the right proportion from A and C. A certain amount of uncontrollable residual interchange between companies would have to be taken up by a suitable agreement and line losses adjusted.

The out-of-phase components of the power flowing from one system to another, which may be more troublesome than the power quantities, will be determined by the resultant effect of (1) the line constants, (2) the relative voltages established in the power houses, A, B and C and at the various substations and (3) of the ratios of the step-up and step-down transformers. There will usually be a strong tendency to put lagging wattless kv-a. on the receiving stations and leading kv-a. in the sending end stations. Most of the difficulties of adjustments involved in interchanging power will arise also in connection with the control of out-of-phase kv-a. but will be easily handled with unitary operation, provided the characteristics of the interconnecting system are always suitable; otherwise abnormal power factors will appear. The considerations discussed above show the strong pressure that will exist for unitary operation in all cases of intricate interconnections.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

NATION-WIDE INDUSTRIAL LIGHTING CAMPAIGN SCHEDULED FOR THE WINTER MONTHS

The illuminating engineer of today is necessarily interested to a surprisingly large degree in the proper application of lighting equipment to the industries. One of the main reasons for this is the fact that the extension and use of the modern standards of lighting have lagged so far behind the development of efficient and effective lighting equipment that even if the latter development were to suddenly cease, there would still be plenty of work for the illuminating engineer for some years to come—merely in increasing and extending the present standards of illumination. From the presidential address given before the annual convention of the Illuminating Engineering Society last October, it becomes apparent that there are several times more men engaged in promoting the commercial aspects of illuminating engineering than there are advancing the technical aspects. In view of this fact, is it any wonder that the Industrial Lighting Campaign this fall will take on a more or less commercial aspect?

This Industrial Lighting Campaign has been called into being partly because of the success of the Home Lighting Educational Campaign of 1924. It is being sponsored by an Industrial Lighting Committee of the National Electric Light Association and has for its aim the education of the owners and managers of industrial plants to the advantages of good industrial lighting. The activity will be nation-wide in its scope and will be conducted by representatives from all branches of the electrical industry. Its main objects will include the following fundamentals:

1. To organize an energetic, direct selling campaign to industrial plants on proper lighting.
2. To plan and make use of an advertising and promotional effort which is unified, and therefore more effective than individual efforts.
3. To go out and sell proper industrial lighting.

These objects will be attained partly through the national organization and partly through the local organizations which are to be formed in the various communities by the local electrical leagues, central stations and the like. The national organization has supervisory control of the entire activity. It will conduct a national campaign on Industrial Lighting advertising in suitable magazines; select and appoint Geographic Chairmen for carrying on the activity locally; furnish sales, lectures and advertising suggestions for local use and will provide field men for the purpose of organizing and assisting local committees.

The local organization will conduct an industrial lighting exhibit and will otherwise attempt to show the advantages of better lighting by means of actual demonstration; it will conduct a local newspaper and direct-mail advertising campaign and will assign possibilities for industrial lighting equipment sales to the proper organizations supporting the local activity.

The activity as a whole will undoubtedly accomplish much in the way of better industrial lighting conditions, for statistics have shown that, out of the thirty million factory sockets in the country, scarcely five million of them are equipped with proper reflectors. In order that a little additional incentive may be offered to the local organizations for their accomplishments and to obtain some detailed information of factory lighting conditions in general, the Industrial Lighting Committee is offering three attractive prizes for the best reports submitted on the activities of local committees. The prize awards will be based on the percentage of factories brought up to a higher standard of lighting in the various communities; the relative value of the report to the rest of the industry as regards facts and figures and the evidence of a truly educational enterprise among industrial plants, civic organizations and the like.

Numerous tests and observations on industrial lighting installations have demonstrated time after time that good lighting has many desirable effects among which are:

1. Increased freedom from accidents.
2. Preservation of eyesight.
3. Promotion of contentment among workers.
4. Increased production for usual payroll.
5. Improved quality of product.
6. Reduced amount of supervision.
7. Greater order and neatness in the plant.
8. Protection of property against depredations.

From the above it will be seen that the industrial lighting campaign, if successful, will greatly benefit the factory owner and worker, and will ultimately benefit the consumer of manufactured products.

JOURNAL OF THE American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE A. I. E. E.
33 West 39th Street, New York
Under the Direction of the Publication Committee

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Subscription. $10.00 per year to United States, Mexico, Cuba, Porto Rico, Hawaii and the Phillipines; $10.50 to Canada and $11.00 to all other countries. Single copies $1.00. Volumes begin with the January issue.

Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

The Pacific Coast Convention an Outstanding Success

The annual Pacific Coast Convention, held in Seattle Sept. 15-19, has passed into Institute history and will long be remembered by the fortunate members and guests who participated as exceedingly profitable from a professional standpoint as well as a most enjoyable event socially.

The technical program was composed of numerous papers of high grade upon a wide variety of interesting topics; the attendance exceeded greatest expectations, there being a registration of 408, from all sections of the country, from beginning to end of each session a large audience was held and much valuable discussion was contributed.

The inspection trips to places of engineering interest and the numerous entertainment events were excellently planned and managed and the visiting members and guests were highly appreciative of the cordial hospitality extended by the Seattle members and ladies of their families.

The convention opened on Tuesday morning, September 15th, Vice-President John Harisberger of Seattle, presiding. The members and guests in attendance were cordially welcomed in an address by Doctor Henry Suzzallo, President of the University of Washington, and to this Doctor Harris J. Ryan, Past-President of the Institute, responded.

National Secretary F. L. Hutchinson then gave a brief address regarding the more recent developments in Institute activities.

At noon on Tuesday a luncheon meeting was held by the Executive Committee of the Northwest Geographical District (No. 9), Vice-President Harisberger Presiding, those in attendance including Chairmen and Secretaries of the Sections within the district or their representatives, representatives of the Sections in the Pacific District (No. 8), and of some of the Student Branches in both Districts; also Past-President Ryan and National Secretary Hutchinson.

This meeting afforded an opportunity for an interesting exchange of views regarding Section, Branch and District activities. The location of next year's Pacific Coast Convention was discussed; Salt Lake City, San Francisco and Portland were proposed but it was decided to leave the decision to the Vice-Presidents of the two districts concerned, who will submit their recommendation to the Board of Directors at a later date, after conferring further with the officers of the Sections concerned.

The first technical session was held Tuesday afternoon, John B. Fisken, of Spokane, presiding. The following papers were presented by the authors or by the members whose names appear in parenthesis:

Stored Mechanical Energy in Transmission Systems by J. P. Jollyman, Pacific Gas and Electric Company, (Roy Wilkins).

Mechanical Design of Spans with Supports at Unequal Elevations by G. S. Smith of the University of Washington.

The Long Span Across the Narrows at Tacoma by J. V. Gongwer and A. F. Darland, both of the Cushman Power Project, Tacoma. (Mr. Gongwer.)

220 Kv. Transmission Transients and Flashovers by R. J. C. Wood, Southern California Edison Company.

These four papers were discussed by Messrs. L. N. Robinson, F. K. Kirsten, R. J. C. Wood, C. E. Magnusson, L. J. Corbett, W. T. Crawford, H. V. Carpenter, G. S. Smith, Roy Wilkins, J. V. Gongwer, C. L. Fortescue, R. W. Sorensen, G. R. F. Nuttall and D. I. Cone; written discussion which had been received from the following was also presented: Messrs. Percy H. Thomas, F. W. Peek, Jr., and J. H. Cox.

On Tuesday evening a reception followed by dancing was held and greatly enjoyed by all members and guests in attendance. The receiving line consisted of Past-President and Mrs. Harris J. Ryan, F. L. Hutchinson, Vice-president, Mrs. John Harisberger, Vice-President and Mrs. P. M. Downing, Mr. and Mrs. John B. Fisken, Doctor and Mrs. C. E. Magnusson, Professor and Mrs. Edgar A. Loew.

At Wednesday morning's session, at which C. A. Heinze of Los Angeles presided, the following papers and discussions were presented:

Fundamental Considerations of Power Limits of Transmission Systems by R. E. Doherty and H. H. Dewey of the General Electric Co. (presented by Mr. Dewey).

The Line of Maximum Economy by E. A. Loew and F. K. Kirsten of the University of Washington (presented by Mr. Loew.)

Transmission Stability—Analytical Discussion of Some Factors Entering Into the Problem by C. L. Fortescue of the Westinghouse Elec. & Mfg. Co.

Steam Power in its Relation to the Development of Water Power by Richard C. Powell of the Pacific Gas and Elec. Company.

These four papers were discussed by Messrs. A. W. Copley, R. J. C. Wood, Roy Wilkins, C. L. Fortescue, Frank G. Baum and C. G. Carey; written discussion was also presented from Messrs. Percy H. Thomas, F. L. Lawton, S. B. Griscom, R. D. Evans, and R. E. Doherty.

Wednesday evening's session was held under the chairmanship of Vice-President Harisberger. A paper *Application of Electric Propulsion to Double-Ended Ferry-Boats* by A. Kennedy, Jr. and Frank V. Smith of the General Electric Company was presented by Mr. Kennedy and discussed by Prof. F. K. Kirsten and Mr. M. J. Whiteman; written discussion was also presented from Mr. H. F. Harvey.

This was followed by an illustrated lecture by Prof. F. K. Kirsten of the University of Washington, *The K-B Propeller*,

with opportunity to the members to inspect various models and discuss the subject further with Prof. Kirsten, personally, immediately after the lecture, an occasion greatly appreciated by a large audience.

At the session on Thursday morning, Prof. E. A. Loew presiding, the following papers and discussions were presented:

Some Features and Improvements on the High Voltage Wattmeter by Joseph S. Carroll, Leland Stanford University

On the Nature of Corona Loss by C. T. Hesselmeyer, Stanford University, and J. K. Kostko of Palo Alto, Cal. (Presented by Ward B. Kindy and Dr. Ryan.)

The Study of Ions and Electrons for Electrical Engineers by Harris J. Ryan, Stanford University.

Engineering Research—An Essential Factor in Engineering Education by C. E. Magnusson, Univ. of Washington.

The Relation Between Engineering Education and Research, with Particular Reference to the California Institute of Technology Plan by W. R. Sorensen, Cal. Inst. of Technology.

A New Departure in Engineering Education by Harold Pender, University of Pennsylvania. (Presented by title).

Discussion upon these six papers was contributed by Messrs. Harris J. Ryan, L. N. Robinson, J. C. Clark, L. J. Corbett, J. H. S. Bates, C. E. Magnusson, C. L. Fortescue, H. V. Carpenter and G. S. Smith.

Thursday afternoon, R. C. Powell, Chairman of the San Francisco Section presiding, the following program was presented:

Distribution Line Practise of the San Joaquin Light and Power Corporation by L. J. Moore and H. H. Minor of the San Joaquin Corporation (presented by Mr. R. E. Cunningham.)

Improvement in Distribution Methods by S. B. Hood, Northern States Power Co.

The 60-Cycle Distribution System of the Commonwealth Edison Company by W. G. Kelley of that company. (Presented by Prof. R. W. Sorensen.)

A High Voltage Distributing System by Glenn H. Smith, Light and Power Dept., City of Seattle.

Verbal discussion of the above papers was contributed to by Messrs. R. E. Cunningham, C. A. Heinze, M. T. Crawford, E. K. Blake, D. I. Cone, and R. J. C. Wood; there was also a written discussion from Paul P. Ashworth.

At 3:30 o'clock the discussion session was discontinued to give an opportunity for the audience to hear a highly inspiring address over the transcontinental telephone lines from New York by Doctor M. I. Pupin, President of the Institute. This address which is printed elsewhere in this issue, was heard perfectly and was acknowledged by a unanimous vote of thanks to Doctor Pupin.

Following Doctor Pupin's adress, Mr. Frank G. Baum presented an illustrated discussion on Mr. R. J. C. Wood's paper given at the Tuesday afternoon session.

Thursday evening, the members and guests met for the principal social event of the Convention in the form of a Dinner-Dance at the Olympic Hotel. Old acquaintances were renewed and new ones made; the dancing, much enjoyed, continued until midnight.

The sixth technical session on Friday morning was presided over by L. W. Ross, Chairman of the Portland Section. The following papers were presented:

Distribution to Supply Increasing Load Densities in Residential Areas by M. T. Crawford, Puget Sound Power and Light Company.

Distribution Practises in Southern California by R. E. Cunningham, Southern Cal. Edison Company.

Power Distribution and Telephone Circuits—Inductive and Physical Relations by M. H. Trueblood, A. T. & T. Co. and D. I. Cone, Pac. T. & T. Co. (Presented by Mr. Cone).

Induction from Steel Lighting Circuits—Effects on Telephone Circuits by R. G. McCurdy, A. T. & T. Co.

Discussion on this group of papers was contributed to by Messrs. R. E. Cunnungham, L. R. Gamble, F. O. McMillan, P. D. Jennings, A. A. Williamson, K. L. Wilkinson, F. H. Mayer, C. A. Heinze and S. B. Hood; with a written discussion from R. R. Cowles and H. S. Phelps.

For the seventh and last technical session of the Convention held Friday afternoon with Vice-President John Harisberger presiding, the program was as follows:

The Radio Interference Problem and the Power Company by L. J. Corbett, Pacific Gas and Electric Co.

Opportunities and Problems in the Electric Distribution System by D. K. Blake, General Electric Co.

Engineering and Economic Features of Distribution Systems Supplying Increasing Load Densities by L. M. Applegate and W. Brenton both of the Portland Electric Power Co. (Presented by Mr. Applegate).

On these papers discussion was contributed by Messrs. H. M. Trueblood, Glen Smith, M. T. Crawford, S. C. Carey and L. J. Corbett, with written discussion from H. P. Miller, R. B. Ashbrook, and H. Richter.

An Annual Golf Tournament of the Pacific Coast members was conducted on Wednesday and Thursday and the John B. Fishken Cup, which is competed for each year, was won by Mr. W. C. Heston, Pacific Coast Editor of the *Electrical World*; the next to best scores were made by Messrs. R. H. Dearborn of the Oregon Agricultural College and Paul M. Downing of the Pacific Gas and Electric Company. Prizes were presented to the winners at the Dinner-Dance on Thursday evening.

A group of Seattle ladies, under the chairmanship of Mrs. C. R. Wallis, was in charge of the various social events arranged especially for the visiting ladies. These included a bridge-tea at the Seattle Yacht Club on Wednesday afternoon. The prize winners here were Mrs. H. L. Eicher of Seattle, Mrs. Ward B. Kindy of Palo Alto, Cal., and Mrs. A. H. Beckwith of Spokane. On Thursday afternoon the ladies enjoyed a drive around Seattle's boulevard system, visiting many places of scenic beauty.

Friday afternoon, the Cornish School, an Institution of National importance in the arts of drama, dancing and music, entertained the Convention visitors with a program followed by a tea in the reception hall of the School. This event was highly enjoyed and appreciated by all in attendance.

Numerous other social courtesies were shown to the visitors and the cordial hospitality of the Seattle members and ladies was a pronounced feature of the Convention throughout the entire week.

Ample opportunity was given for inspection trips to nearby places during the Convention and a large number of members remained until Saturday to participate in several trips that the Convention Committee had arranged to more distant plants and developments of engineering interest.

The Convention Committee responsible for the planning of the Convention consisted of Messrs. Geo. E. Quinan, *Chairman*, C. N. Beebe, H. W. Clark, H. P. Cramer, W. C. Du Vall, F. R. George, C. A. Heinze, Chas. A. Lund, Jas. S. McNair, L. W. W. Morrow and the following Seattle members who were chairmen of sub-committees in charge of the activities indicated below: C. E. Magnusson, Convention Papers; C. R. Wallis, Entertainment: C. E. Mong, Publicity; E. J. Des Camp, Golf; John Harisberger, registration and Hotels; Joseph Hellenthal, Transportation. The committee members were also assisted by numerous other Seattle members and ladies who contributed materially toward this highly successful convention.

New York Section Meeting

The first meeting of the New York Section of the A. I. E. E. for the administrative year 1925-26 will be held in the auditorium of the Engineering Societies Building, 33 West 39th St., New York, on the evening of Friday, October, 23, 1925.

Two papers of unusual interest are to be presented, as follows:

1. *Three-Phase, 60,000-Kv-a. Turbo Alternators for Gennevilliers* by C. Roth, Chief Electrical Engineer, Société-Alsacienne de Constructions Mecaniques, Belfort, France.

2. *Hydrogen as a Cooling Medium for Electrical Machinery* by Edgar Knowlton, Chester W. Rice and C. H. Freiburghouse, all of the General Electric Co.

Both of the above papers have been published in the JOURNAL (July and September issues) and live discussion by authorities in the field may be anticipated. Following the prepared discussion the meeting will be thrown open to general discussion.

First Meeting of New York Electrical Society

The New York Electrical Society will hold its first meeting for the administrative year 1925-26 on the evening of Wednesday, October 7, 1925 in the auditorium, Engineering Societies Building, 33 West 39th Street, New York.

The meeting will be devoted to two papers on subjects of great interest not only to those in the electrical field but to the general business man as well. They will be as follows:

1. *Electric Protection Against Burglary of Bank Vaults, Safes, Jewelry, Silk, Fur and Other Stores* by W. B. Manson, Chief Engineer, Holmes Electric Protective Company.
2. *Electric Supervision of Store and Warehouse Sprinkler Systems* by C. C. Johnson, Vice President and Chief Engineer, American District Telegraph Company.

Both of these papers will be accompanied by an exhibition of apparatus and working demonstrations. All interested are cordially invited to attend.

Election of Officers of A. I. E. E.

The amendments to the Constitution and By-laws of the Institute, as recently adopted and now in force, provide as follows:

Constitution

28. There shall be constituted each year a National Nominating Committee consisting of one representative of each geographical district, elected by its Executive Committee, and other members chosen by and from the Board of Directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the By-laws: The National Secretary of the INSTITUTE shall be the secretary of the National Nominating Committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as Vice-President of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The National Nominating Committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The National Nominating Committee shall name on or before December 15 of each year, one or more candidates for President, Treasurer and the proper number of Managers, and shall include in its ticket such candidates for Vice-Presidents as have been named by the nominating committees of the respective geographical districts, if received by the National Nominating Committee when and as provided in the By-laws; otherwise the National Nominating Committee shall nominate one or more candidates for Vice-President(s) from the district(s) concerned.

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the National Secretary when and as provided in the By-laws; such petitions for the nomination of Vice-Presidents shall be signed only by members within the district concerned.

32. During the first week in March of each year the National Secretary shall mail to all qualified voters an official ballot on which are to be listed all eligible candidates, nominated as provided in Sections 30 and 31. The candidates of the National Nominating Committee shall be appropriately designated as such. Any nominee may, prior to the printing of the ballots, withdraw his name by written request to the National Secretary, whereupon that fact shall be suitably indicated upon the ballot.

The voting for each office shall be restricted to the nominees for that office as printed on the ballot. The ballot shall be acompanied with an envelope on which shall be printed the title of the Institute, the name and address of the National Secretary and the words, "Official Voting Envelope—Enclosing a Ballot Only." All names voted for shall be written, printed or otherwise marked on a single ticket or ballot, which shall be enclosed in a sealed, unmarked and unidentified inner envelope of any suitable character, which shall in turn be enclosed either in the "Official Voting Envelope" (received from the National Secretary) or any other envelope, marked on its face, "Non-Official Voting Envelope—Enclosing a Ballot Only." The outer envelope of either class shall be identified by the name of the sender on its face, shall be sealed, and in order to be counted, shall reach the National Secretary not later than the first day of May.

By-Laws

SEC. 21. During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 1st of that year the Executive Committee of each District must select a member of that District to serve as a member of the National Nominating Committee and shall, by November 1st, notify the Secretary of the National Nominating Committee of the name of the member selected.

During September of each year, the Secretary of the National Nominating Committee shall notify the Chairman of the Executive Committee of each Geographical District that by November 15th of that year a nomination for a Vice-President from that District, made by the District Executive Commitee, must be in the hands of the Secretary of the National Nominating Committee.

Between October 1st and November 15th of each year, the Board of Directors shall choose five of its members to serve on the National Nominating Committee and shall notify the Secretary of that Committee of the names so selected, and shall also notify the five members selected.

The Secretary of the National Nominating Committee shall give the fifteen members so selected not less than ten days' notice of the first meeting of the committee, which shall be held not later than December 15th. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the National Nominating Committee must be received by the Secretary of the committee by November 15th. The nominations as made by the National Nominating Committee shall be published in the January issue of the A. I. E. E. JOURNAL, or otherwise mailed to the INSTITUTE membership during the month of January.

A. I. E. E. Standards

MANY REVISED SECTIONS NOW AVAILABLE

The work of revision of the 1922 edition of the A. I. E. E. Standards, which has been in progress for several years, has now reached a stage where a large number of sections of the Standards have been approved by the Board of Directors and are available.

The present plan under which the Institute Standards are being issued involves the separation of the complete body of Standards into forty—or more—sections, each published as a separate pamphlet and dealing with a specific subject. Each section of the Standards has been formulated by a Working Committee of the Standards Committee which has been made as representative as possible for the work in hand and each section contains not only revised material but in many cases, new material. The division of the Standards into a number of

separate publications simplifies the process of keeping the Standards revised to conform with the latest developments and enables those interested in a particular field to obtain in concise form the material relating to that field.

A list follows giving the approved available Sections and the prices at which they may be obtained.

Members of the A. I. E. E. and Public Libraries are entitled to 50% discount from list prices on one or more copies. A discount of 25% to publishers and subscription agents, and non-member purchasers of ten or more copies.

For further information a second list of "Sections in Preparation" is also given. In this list one section, No. 9, "Induction Motors and Induction Machines in General," may be obtained without charge. It is issued for the purpose of obtaining all possible criticisms and suggestions previous to adoption as a Standard.

Many members will probably wish to secure a binder for the Standards pamphlets. A notice has been mailed to the membership giving full details relative to such a binder and asking that orders be filed at Institute headquarters.

SECTIONS OF THE A. I. E. E. STANDARDS

Available Adopted Sections

No. 1 (April 1925) General Principles upon which Temperature Limits are based in the Rating of Electrical Machinery. Price 20 cents.

5 (July 1925) Standards for Direct-Current Generators and Motors and Direct-Current Commutator Machines in General. Price 40 cents.

7 (July 1925) Standards for Alternators, Synchronous Motors and Synchronous Machines in General. Price 40 cents.

8 (March 1925) Standards for Synchronous Converters. Price 40 cents.

10 (July 1925) Standards for Direct-Current and Alternating-Current Fractional Horse Power Motors. Price 30 cents.

11 (July 1925) Standards for Railway Motors. Price 30 cents.

13 (August 1925) Standards for Transformers, Induction Regulators and Reactors. Price 40 cents.

14 (March 1925) Standards for Instrument Transformers. Price 30 cents.

15 (Dec. 1924) Standards for Industrial Control Apparatus. Price 40 cents.

16 (July 1925) Standards for Railway Control and Mine Locomotive Control Apparatus. Price 40 cents.

19 (July 1925) Standards for Oil Circuit Breakers. Price 30 cents.

22 (July 1925) Standards for Disconnecting and Horn Gap Switches. Price 30 cents.

34 (June 1922) Standards for Telegraphy and Telephony. Price 30 cents.

36 (June 1922) Standards for Storage Batteries. Price 20 cents.

37 (July 1925) Standards for Illumination. Price 30 cents.

38 (March 1925) Standards for Electric Arc Welding Apparatus. Price 40 cents.

39 (July 1925) Standards for Electric Resistance Welding Apparatus. Price 30 cents.

41 (July 1925) Standards for Insulators. Price 30 cents.

42 (March 1924) Standard Symbols for Electrical Equipment of Buildings. Price 20 cents.

Sections in Preparation

No. 2 Standard Definitions and Symbols.

4 Standards for the Measurement of Test Voltages in Dielectric Tests.

9 Standards for Induction Motors and Induction Machines in General.

12 Standards for Prime Movers and Generator Units.

20 Standards for Air Circuit Breakers.

21 Standards for Lever Switches and Enclosed Lever Switches.

27 Standards for Switchboards.

28 Standards for Lightning Arresters.

29 Standards for Electric Railways.

30 Standards for Wires and Cables.

31 Standards for Transmission Lines and Distribution Lines.

32 Standards for Meters.

33 Standards for Electrical Measuring Instruments.

35 Standards for Radio Communication.

Farewell Dinner to Doctor Dwight

On Wednesday, September 9th, a party of about forty Canadian Westinghouse engineers, under the chairmanship of their chief, H. U. Hart, met for dinner at the Hamilton Club, to bid farewell to Doctor Herbert Bristol Dwight before he should leave to take up his work as Professor of Electrical Engineering at the Massachusetts Institute of Technology. Beside the chairman, the speakers were C. H. Pook, manager of the works at Hamilton, C. A. Price, Assistant Chief Engineer, C. H. Mitchell, H. M. Bostwick, D. P. Brown and L. B. Chubbuck. Doctor Dwight made a fitting response to the addresses of the evening and the dinner party adjourned to the further enjoyment of a theater party.

As a token of their esteem, a number of his engineer friends presented Doctor Dwight with a traveling case. He has already left for Boston to assume his new duties there.

Doctor Dwight is the author of numerous books of value to the profession; a review of one of these entitled, *Transmission Line Formulas*, appears in this issue of the JOURNAL.

M. I. T. Adds Another Public Utility Interest to Its Cooperative Course

With the opening of the fall term, the Massachusetts Institute of Technology has taken another important step by special arrangements with the Bell Telephone System. A carefully selected group of students who have successfully completed the first two years of the regular course in electrical engineering or its equivalent at other institutions, will be sent to New York for four months' service with the Bell Telephone System, part of which time they will be occupied at the plant of the Western Electric Company, Kearney, N. J., learning the actual detail of telephone appliances.

No employment contract is made between students and the company, and at the completion of their course, graduates are left free to avail themselves in accordance with their own personal preferences of whatever offers come to them.

John Scott Medal to William C. Houskeeper

The City of Philadelphia has awarded to William G. Houskeeper of South Orange, N. J., the John Scott medal for his contribution to technical progress. The award carries with it a premium of $1000 and is made by the City of Philadelphia from the proceeds of a fund left more than one hundred years ago by John Scott of Edinburgh, Scotland.

The achievement for which the medal was awarded to Mr. Houskeeper is the development in the Bell Telephone Laboratories, New York, of a practical method for making an air-tight joint between copper and glass. Such a seal has been sought ever since

the invention of the electric lamp more than a generation ago, requiring that an electric current be carried into the inside of an exhausted glass bulb. Recent developments in high power radio transmission have required the carrying of even larger currents into vacuum tubes, and in other ways indicated the necessity for a copper-to-glass seal.

It has been known for a long time that these two substances when heated and pressed together will adhere much as taffy will stick to a plate. The fact that on cooling the copper contracted more rapidly than the glass invariably caused the joint to break and allowed air to leak in and destroy the vacuum.

Since platinum contracts at practically the same rate as glass it has been extensively used for lead-in wires. Its cost, however, is prohibitive where large amounts must be used. Mr. Houskeeper's invention makes it entirely practicable to use copper instead of platinum, thus making the large sized vacuum tubes commercially possible. Many of these tubes are in use in the high powered radio broadcasting stations.

Mr. Houskeeper's invention briefly consists in the discovery that a copper-glass seal fails by the shrinkage of the copper away from the glass, and that this shrinkage can be prevented if either of the two substances is thin enough in comparison with the other that it can be stretched or compressed by its heavier teammate. Due to its greater ductility the copper is usually selected as the element to give.

In joining a copper tube to one of glass the end of the copper is worked to a thin fin, only a few thousandths of an inch thick. This is rubbed into contact with a heated glass ring, and later a larger piece of glass is sealed to the ring to complete the upper part of one of the high power vacuum tubes, such as are used in many broadcasting stations. The lead-in wires are brought through this tube in an equally ingenious manner. To each wire is welded a thin copper disk which is then rubbed into contact with the flared end of a short glass tube. The other end of the tube is then welded by an ordinary glass-to-glass joint to the the upper part of the vacuum tube.

AMERICAN ENGINEERING COUNCIL

Administrative Board Meeting

The next meeting of the Administrative Board of the American Engineering Council will be held in Columbus, Ohio, October 29 and 30, under the auspices of the Engineers Club of Columbus. The President, James Hartness, former Governor of Vermont, who has been recovering from a prolonged illness following an operation in a Boston hospital, is expected to preside.

The first session of the Board will begin at 10 a. m. on Thursday, October 29. The Executive Committee will meet Wednesday, October 28.

Chief among the topics to come before the Board is the study of commercial aviation now being made by the Council jointly with the Department of Commerce. Numerous reports of other activities of the Council will also be presented.

Chicago Office of Employment Service Opens

The Engineering Societies Employment Service, under the direction of the secretaries of the four National Societies of Civil, Mechanical, Mining and Electrical Engineers, working in conjunction with the Western Society of Engineers, have opened an office in Chicago. By this arrangement service is more widely available to all members of the four Founder Societies as well as to the members of the Western Society of Engineers and it is felt that this will materially broaden the field both for those desiring positions and those with positions to fill. The Chicago office is under the management of A. K. Krauser, Room 1736, 53 West Jackson Boulevard, Chicago, Ill. (Telephone 1238 Harrison). The New York Office will continue at 33 West 39th St., New York (Telephone Pennsylvania 9220) under the management of W. V. Brown.

ENGINEERING FOUNDATION

The $100,000 Arch Test Dam

Plans featuring the concrete arch test dam to be erected on Stevenson Creek about 60 miles from Fresno, have been received at Institute Headquarters. These show some of the unique engineering achievements to be introduced into this structure, and give general dimensions, location and application of test pressures to be used in this gigantic investigation of structural values being undertaken in the interest of engineering accomplishment.

Obituary

Alan C. Crago, Associate, died September 14th after a brief illness. Mr. Crago was born in South Sharon, Pa., in 1901. His general education was through the Wilkinsburgh High School in 1919, followed by an electrical engineering course at Carnegie Institute of Technology, from which he was graduated in 1923 with a degree of B. S. He was also a graduate student engineer from the training course of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, and was serving them in the capacity of research engineer at the time of his death. He was about to leave for a year's course at the California Institute of Technology, and his work bore signs of great promise. Mr. Crago was joint author of the paper *Corona in Oil* presented at the last Midwinter Convention of the Institute. He was elected an Associate of the Institute November 1924.

Charles Frederic Chandler, for many years Professor of Chemistry at Columbia University, died suddenly of heart failure early in September 1925 in the 89th year of his age. Born at Lancaster, Mass., December 6, 1836, Doctor Chandler passed through the New Bedford High School and entered the Lawrence Scientific School, Harvard College. He later studied at the University of Goettingen and the University of Berlin, and received his degree of Doctor of Philosophy in 1856. Upon completing his course he immediately became a college professor, engaged in teaching chemistry and physics and delivering regular courses of lectures on electricity every winter. Thomas A. Edison was one of Doctors Chandler's sponsors for membership when he joined the Institute in 1891, as an Associate; the following year he changed his grade to Member.

PERSONAL MENTION

Philip P. Ash has been promoted to the position of chief signal draftsman of the Louisville and Nashville Railroad Company, Louisville, Ky.

S. M. Umar, B. E., previously State Electrical Engineer of Bhopal, Central India, is now engaged by the firm, Bergmann Elektricitat Werke, Berlin, Germany.

G. Case Geraty, Jr., formerly electrical engineer and estimator for the Electrical Contracting Company of Chicago, is now associated with the Chicago office of the Public Service Company of Northern Illinois.

Charles Diehm, previously with the Philadelphia Electric Company, has assumed new duties with the Electro Dynamic Company of Bayonne, N. J., as assistant to their production manager.

R. L. Chapmam has returned to the General Electric Company from the C. M. & St. P. Railway where he served as electrician on heavy traction on their electrified division. He is now in the Railway Locomotive Department of the General Electric Company's home office.

Edward F. Cary formerly with Dwight P. Robinson, Inc., at Pittsburgh, Pa., has received an appointment as Supervisor of Electrical Construction in the Department of City Transit, City of Philadelphia, and is now in charge of the electrical work on the new subway construction, Broad Street, that city.

Robert H. Marriott has resigned from the employ of the U. S. Navy and is now a consulting engineer with offices in New York City. For the past ten years he has been an expert radio aid and radio engineer for the Navy in Northwestern United States and Alaska. For three years previous to that he was U. S. Radio Inspector in New York. Prior to becoming radio inspector in New York, he was engineer for several commercial radio companies back to 1901, the date of his graduation from Ohio State University where he had specialized in wireless communication and the work of Hertz. Mr. Marriott has actively followed wireless and radio engineering in this country since the late nineties. He built some of the earlier commercial radio stations in the United States and was one of the founders and first president of the Institute of Radio Engineers.

Addresses Wanted

A list of names of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Clyde E. Bentley, 2815 Kelsey St., Berkeley, Calif.
2.—Angus Black, 1237 Pacific St., Brooklyn, N. Y.
3.—Paul H. Burkhart, S. S. S. Yale University, 10 Hillhouse Ave., New Haven, Conn.
4.—Manuel W. Dans, Apt. 6, 519 West 134th St., New York, N. Y.
5.—Edward C. Hanson, Dixville, Quebec, Canada.
6.—Louis J. McBane, 1336 Oak St., N. W. Washington, D. C.
7.—Carl H. Struth, 527 West 124th St., New York, N. Y.
8.—H. Thompson Whaler, 190 S. E. 12th Terrace, Miami, Fla.

A Memorial to Professor Alexandre S. Popov

The April 1925 issue of the Russian publication, *Electritchestvo*, has been dedicated to the memory of Professor Alexandre S. Popov and thirty years of wireless telegraphy.

This is a publication founded in 1880 by the Electrical Section of the Societe Technique Russe and is the organ of Electrical Industries, the Superior Council of National Economy, the Electrical Section of the Russian Technical Society,—the leading electrotechnical societies of Russia, including the International Electrotechnical Commission. An interesting article on the unusual achievements of this famous Russian mathematician and scientist is given in the memorial issue.

Book Reviews

Transmission Line Formulas.

Second edition, revised and enlarged; illustrated; D. Van Nostrand. 215 pp., 6 by 9 in.; cloth; price, $3.00 net.

A book of unquestionable worth to the profession is Doctor Herbert Bristol Dwight's work entitled *Transmission on Line Formulas*. This is already in its second edition; a book giving the engineer a set of instructions by which he may be enabled to make good electrical calculations for transmission lines with the least possible amount of labor. Charts, tables of formulas and tables of line constants have been so arranged as to make their application convenient and efficient. Also a number of chapters have been included wherein the derivation of the principal working formulas is given.

A Graphic Table Combining Logarithms and Anti-Logarithms.

By Adrien Lacroix and Charles L. Ragot, the Macmillan Book Company, New York; 46 pp., 7 by 10 in; cloth.

This is a small volume giving, without interpolation, the logarithms to five places of all five-place numbers and numbers to five places corresponding to all five-place logarithms; also graphic tables reading to four places, thus avoiding the necessity of recourse to the process of interpolation, which at best, is involved and therefore entails considerable source of error. The simplicity with which they may be read and the elimination of auxiliary tables of proportional parts make these graphic tables more convenient, more rapid and more reliable than the other forms of logarithmic tables. The work is, however, more graphic than tabular.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

(BOOK NOTICES, SEPTEMBER 1-30)

Allgemeine Grundlagen der Elektrotechnik.

By C. Michalke. Ber. u. Lpz., Walter de Gruyter & Co., 1925. (Siemens-Handbücher, Bd. 1). 167 pp., illus., 8 x 6 in., cloth. 5.-gm.

This volume is the first of a series of handbooks to be published by the Siemens & Halske and Siemens-Schuckert companies and is the work of the chief engineer of the Siemens-Schuckert Works. The little book is intended for a wide circle of readers, including both those without technical education and those whose daily occupation in a special field has caused them somewhat to lose touch with the general theory of electricity.

The work is not a textbook but rather a convenient work of reference for those who wish information on the principles of applied electricity or one of its branches, or who wish to refresh their college training for practical use.

LIGHT, PHOTOMETRY AND ILLUMINATING ENGINEERING.

By William E. Barrows, N. Y., McGraw-Hill Book Co., 1925. 412 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

This book is designed for use as a textbook in illuminating engineering and as a practical reference book. It is based on the previous books by the author on illumination, but approximately two-thirds of the present text is new. The author has attempted to assemble the best opinion on artificial illumination and the choice of equipment for lighting.

ELECTRICAL PRECIPITATION.

By Sir Oliver Lodge. Lond., Oxford University Press; Humphrey Milford, 1925. (Institute of Physics. Physics in industry, v. 3). 40 pp., plates, tables, 10 x 6 in., boards. $1.00.

The lecture deals with the natural precipitation of atmospheric moisture as rain or mist and with the artificial precipitation of dust and fumes by electrical methods. The attendant physical phenomena are considered and explained. The author then proceeds to contemplate the possible modification, in the future, of atmospheric and meteorological phenomena by combining natural and artificial precipitation. An appendix gives some notes on commercial installations of precipitating apparatus.

LE RADIUM ET LES RADIO-ELEMENTS.

By Maurice Curie. Paris, J. B. Bailliere et Fils, 1925. 354 pp., illus., diagrs., 9 x 6 in., paper. 40 fr.

Dr. Curie's book differs in scope from most others on this subject. It is concerned with the industrial rather than the scientific aspects of radioactive substances and is intended particularly for those engaged in the industry.

The book opens with a brief review of the important theoretical facts and a chapter on methods of measuring radioactivity. The remainder of the work treats of the occurrence and mining fo radioactive minerals and the methods of concentrating and preparing them for use, of the applications of the radio-elements in medicine, of the production of luminous materials and of the uses of radioactive substances in agriculture.

GRUNDLAGEN UND NEUERE FORTSCHRITTE DER ZAHNRAD-ERZEUGUNG.

By Karl Kutzbach. Berlin, V. D. I. Verlag. 1925. 70 pp., illus., diagrs., tables, 10 x 7 in., paper. 5.-mk.

Professor Kutzbach's pamphlet discusses the fundamentals of the whole field of the generation of gearing in a practical way, suited to the needs of students and designers. Recent processes of gear making are described, and a comprehensive view of present practice in design and manufacture is given. There are appendixes explaining the usual notation and on the correction of tooth profiles.

PAST SECTION MEETINGS

Columbus

Oil Engines, Combustion Processes and Gas Engines, by H. F. Shepard and J. F. Dykstra, Springfield, Ohio, and

Oil-Engine Locomotives, by L. H. Morrison, New York City. The meeting, including dinner, was held at the Ohio State University. April 24. Attendance 40.

Electric Motor Control, by F. R. Fishback, Electric Controller & Mfg. Co. Illustrated. The following officers were elected: Chairman, R. J. Feather; Secretary, W. T. Schumaker. May 29. Attendance 18.

St. Louis

Spot Welding, by J. A. Osborn, American Car and Foundry Co. May 6. Attendance 76.

A humorous talk was given by L. A. Parker, Jefferson City, Mo. The following officers were elected: Chairman, F. D. Lyons; Secretary, Ralph E. Toensfeldt. Refreshments were served. May 27. Attendance 125.

PAST BRANCH MEETING

Drexel Institute

Business and Social meeting. The following officers were elected: President, Edwin B. Middleton; Vice-President, Earl F. Blinn; Secretary, William N. Richards; Treasurer, Charles Robb. May 29. Attendance 27.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.

53 West Jackson Blv'de., Room 1736, Chicago, Ill., A. K. Krauser, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

DISTRIBUTION SUPERINTENDENT OR ENGINEER, experienced and competent to handle design, construction, operation and maintenance of overhead and underground electrical distribution system, substations and transmission lines. Must have executive ability and be able to handle organization. Apply by letter stating age, education, experience in detail, salary expected and references. Location, South. R-7275.

ENGINEER AND PATENT ATTORNEY, having knowledge of electricity, chemistry, and electron physics for development and patent work on vacuum and similar devices, with large corporation. Analytical ability, good judgment and tact essential. Apply by letter stating education, experience, age and salary expected. Location, East. R-6794.

MANAGER, for department for the development of transformers and other high-tension apparatus. Should have some technical experience in the design, and manufacture of such apparatus, and experience in pushing forward new development work. Apply by letter. Location, Connecticut. R-7164.

SALES ENGINEER, to handle distribution and power transformers for public utilities trade. Must have sales experience and be a native of New England. Apply by letter only. Salary proposition. Location, New England. R-7406.

ELECTRICAL SALES ENGINEER, for company manufacturing carbon brushes and generators, and carbon specialities. Locations, Kansas, St. Louis, Missouri, Birmingham, Alabama and Atlanta, Georgia. R-5406.

MEN AVAILABLE

PLANT ENGINEER OR SUPERINTENDENT OF POWER AND MAINTENANCE, 39 years of age, technical graduate. General electric test and all around power and maintenance experience. Available September 15th. Location immaterial. A-3854.

ELECTRICAL ENGINEER, 28 years of age, with over 7 years of broad experience in electric

utilities and allied industries. Desires permanent connection with some utility operating in a town of about 50,000 population in the Middle West. C-326.

ELECTRICAL ENGINEER, college graduate with six years of practical experience, mostly in testing station machinery and control apparatus with large public utility company. Work done in connection with acceptance, maintenance, emergencies, plant tests and research. Desires permanent position where experience can be used to advantage. Location preferred, Metropolitan District. B-8818.

ELECTRICAL ENGINEER, age 36, with experience in construction and maintenance of public utilities, power plants and substations, also seven years' experience on construction and maintenance of industrial plants. Desires position with either of the above companies. Five years with present employer. Can handle men and get results. C-240.

ENGINEER-SCIENTIST, age 30, married, educated at M. I. T.; three years in chemistry, three years in mathematical physics, graduating in mechanical engineering. Employed as technical report writer for research laboratory of General Electric, and as industrial physicist and designer by Corning Glass Works. Executive experience and broad training in commercial subjects. Employed. B-9930.

GRADUATE ELECTRICAL ENGINEER, E. E. 1924, age 22, single, desires engineering position in Florida or California, position with a small, rapidly growing, private concern with a good chance for advancement preferred. One and one-half years' experience in the engineering department of a large public utility operating in New York City with whom he is at present connected. Available January 1, 1926. B-8793.

ENGINEER, E. E., M. E., age 29, married, experienced in mechanics, design, estimating and field supervision o substations, switching structures, hydro-electric and steam station electrical installations. Familiar with underwriters regulations, modern safety practices and economic methods. Executive ability. Location, East. Salary $3600. B-5505.

ELECTRICAL ENGINEER, age 30, married, eight years' experience station and sub-station design and construction supervision. Isolated phase layout, wiring diagrams, relay problems. Available reasonable notice. New England and New York states preferred. C-303.

ELECTRICAL ENGINEER, age 28, unmarried, graduate Mass. Institute Technology, A. B. degree. Experience small central station installations, was Marconi operator before and naval radio electrician during War. Past three years charge instruction radio communication, design, construction, installation, operation radio station large state university. Prefers experimental or development in communication. Location anywhere. C-354.

ASSISTANT ENGINEER, age 32, married, Cornell graduate '16, M. E. and E. E., eight years' experience in design and installation of electrical and mechanical equipment, one year and a half of consulting engineering work on power house and heavy machinery. Available in two weeks. Location anywhere in United States or Canada. B-6552.

TECHNICAL GRADUATE in electrical engineering and chemistry, with thirteen years' experience, the greater part of which has been spent in research and development work. Desires position with congenial surroundings requiring creative ability with good technical training and basic practical experience. Age 30, married. B-8987.

ELECTRICAL ENGINEER, age 28, married, six years mechanical and electrical design and drafting, power house construction, material requisitions. Desires position anywhere in United States, prefers New York City. B-4217.

ELECTRICAL ENGINEER, technical graduate, Canadian, married, age 32, two years manager branch service station of large electric corporation, two years assistant to plant engineer in manufacturing plant, several months' experience in car barns of electric railway. Desires position with electric railway, or manufacturing concern. Prefers combined engineering and administrative position. Available on reasonable notice. B-9801.

ELECTRICAL ENGINEER, American origin, Christian, age 37, technical graduate, with unusual business training and experience. Eight years of successful invention and commercial design of electrical and mechanical apparatus, including radio. Executive ability. Would head development of new or improved apparatus and specialties with view of sharing profits. Minimum salary $6000. A-2817.

GRADUATE ELECTRICAL ENGINEER with ten years' experience in drafting, electrical and mechanical design, testing, trouble shooting; also experienced in handling of instruments and management of crews. Age 36, married. Desires situation in Ohio or Florida, but other locations considered. C-374.

ELECTRICAL ENGINEER, Rice graduate and General Electric Test Course, fourteen years' experience in house wiring, testing, turntables, drawbridges, electric furnaces and other kinds of electrical work. Specialist on house wiring, and until recently partner in plumbing and electric contracting firm. Location immaterial. C-389.

ELECTRICAL ENGINEER, age 29, at present employed but desires to change. Six years' experience public utility company design A. C. substations, also supervised design small automatic distribution station. In addition to designing have supervised specifications for material to be purchased in various substations of company. Would like connection with public utility company, or consulting engineer vicinity New York City. A-4769.

ELECTRICAL ENGINEER, M. E., seeks opportunity in New York district. Twenty years in invention, design and manufacture of electrical apparatus and mechanical devices. Experienced in telegraph, telephone, radio, marine and other lines, also installation and selling. Now executive in development of accounting machinery. Available about December 1st. B-5948.

ELECTRICAL AND MECHANICAL ENGINEER, age 40, married, technical university graduate, fifteen years of practical experience in the design, test and operation of a-c. and d-c. motors, generators and switchboard panels; elevator construction, hoisting equipment and installations. Development and production work. Available on reasonable notice. Location, New York City or vicinity. B-5240.

ELECTRICAL ENGINEERING GRADUATE, age 28, single, wishes position with engineering or construction firm where the following experience can be used to advantage. One and one-half years' experience on bridges, conveyor equipment, one year test and assembly electrical motors, one year test and assembly storage batteries. Great adaptability; hard worker. Available immediately. Location immaterial. B-7908.

ELECTRICAL ENGINEER, age 27, B. S. graduate. At present factory sales and service representative for nationally known storage battery company. Wide practical service experience, especially automotive and telephone; three years' broad experience in successfully developing own business. Desires engineering proposition, preferably sales and service where real effort and executive ability have opportunity. New Hudson Coach available for business. C-75.

KANSAS GRADUATE, age 32, married, twelve years' broad engineering and executive experience since graduation, including educational work, electric railway maintenance, army service as captain during War, telephone engineering. Employed last five years in preparing plans, estimates and specifications for manual telephone equipment. Desires change with future. B-9568.

ELECTRICAL ENGINEER AND CONSTRUCTION SUPERINTENDENT, age 32, single, extensive experience charge of design and construction power house, substation, underground, general construction. Recently electrical superintendent constuction super power plant and construction superintendant large 110,000-volt outdoor substation. Available at once. Location anywhere. C-421.

POWER SALES ENGINEER, specialist in large power contracts, rate analyses and public service commission cases. Available upon thirty days' notice. Minimum salary $6000. B-4221.

EXECUTIVE-ENGINEERING GRADUATE, ten years' experience in the management of technical, new business and merchandising departments of utilities. Particularly efficient in load and revenue building. Will consider the management of a property, preferably not operated by a syndicate. Your opportunity to secure an all round executive to take complete charge of light and power property. C-420.

ELECTRICAL ENGINEER, executive, broad experience engineering and manufacturing field. Expert development and design of small apparatus and instruments, pyrometry. Manufacturing methods, standardization, quantity production, planning, factory organization and plant layouts. Desires connection with manufacturing concern, consulting or industrial engineer operating in manufacturing field. American, Christian. B-2721.

STUDENT A. I. E. E., extensive technical training, age 22, desires position as student engineer with public utility. Would consider manufacturing or hydroelectric concern. One year's experience controller testing. Location, Western States, preferably Colorado. Salary secondary importance. Available ten days' notice. C-416.

ELECTRICAL ENGINEER, age 26, married, graduate E. E., three years' experience laboratory and office work as engineering assistant to department head in low power circuit work, also some design of small mechanisms. Desires engineering position with possibilities of advancement. Employed. Available on reasonable notice. Location, New York City or Northern New Jersey. C-321.

MEMBERSHIP

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1925.

Anderson, R. P., The Washington Water Power Co., Spokane, Wash.
Baird, A. F. University of New Brunswick, Fredericton, N. B.
Baughn, E., The Washington Water Power Co., Spokane, Wash.
Betz, C. A., The Ohio Power Co., Newcomerstown, Ohio
Brice, G. W., American Tel. & Tel. Co., Key West, Fla.
Browne, D. J., Jr., Bell Tel. Co. of Penna., New Kensington, Pa.
Chomeau, H., Jr., Electric Storage Battery Co., St. Louis, Mo.
Cooper, S. J., Marconi Co., Montreal, P. Q., Canada
Cristal, C. W., Cleveland Union Terminal Co., Cleveland, Ohio
Currey, W. C., Interborough Rapid Transit Co., New York, N. Y.
Davis, H. J., Port of Portland Drydocks, Portland, Ore.
Dietze, I. C., Bureau of Power & Light, Los Angeles, Calif.
Edelen, H. W., The Pacific Tel. & Tel. Co., San Francisco, Calif.

Eicher, F. C., Edward Ford Plate Glass Co., Rossford, Ohio
Ellis, W. J., Jr., The Ohio Power Co., Canton, Ohio
Fowler, A., Hydro Electric Power Commission, Toronto, Ont. Can.
Fowler, A. D., U. S. Engineer Office, Florence, Ala.
Frank, E., New York Edison Co., New York, N.Y.
Freeman, O. M., The New York Edison Co., New York, N. Y.
Gallagher, J. D., Underwriters' Laboratories, Chicago, Ill.
George, N. N., Twin City Rapid Transit Co., St. Paul, Minn.
Hasenpflug, R., 2261 Andrews Ave., New York, N. Y.
Herdman, W. J., (Member), Postal Telegraph-Cable Co., New York, N. Y.
Hill, H. F., Public Utilities & Industrial Corp., Brookline, Mass.
Hodgson, C., (Member) Public Service Co. of No. Ill., Chicago, Ill.
(Applicant for re-election.)
Hoffman, E. C., Precise Mfg. Corp., Rochester, N. Y.
Hopkins, L. C., Mansell-Hunt & Catty, Hoboken, N. J.
Hulcher, T. T., Thos. T. Hulcher Machine Works, Richmond, Va.
Idrau, C. M., Public Service Production Co., Newark, N. J.
Kirk, W. W., Delta Star Electric Co., Los Angeles, Calif.
Krueger, H. G., Commonwealth Edison Co., Chicago, Ill.
La Marsh, W. H., New York Edison Co., New York, N. Y.
Lang, J. O., The Dayton Power & Light Co., Dayton, Ohio
Lane, F. B., Ford Motor Co., Detroit, Mich.
Lapp, R., The Edward Ford Plate Glass Co., Rossford, Ohio
Loehr, J. E., New York Edison Co., New York, N. Y.
Marie, G. W., Century Electric Co., St. Louis, Mo.
Martin, F. G., W. L. Hutchison Electric Co., Kansas City, Mo.
Maunder, S. T., General Electric Co., Pittsfield, Mass.
Mellinger, M. C., (Member), American Smelting & Ref. Co., Rosita, Coahuila, Mexico
Moore, J. A., New York Rapid Transit Commission, Brooklyn, N. Y.
Mullison, J. H., (Member), Hutchinson District United Power & Light Corp., Hutchinson, Kans.
Muzzy, L., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Neblett, W. R., Jr., Memphis Power & Light Co., Memphis, Tenn.
Norman, N. C., Bell Telephone Laboratories, New York, N. Y.
Olson, M. S., Carver Radio & Electric Laboratory, Carver, Minn.
Oropesa, P., School of Electrical & Mechanical Engg., Mexico City, Mex.
Partridge, K. L., Hartford Electric Lt. Co., Hartford, Conn.
Phelps, W. H., Omaha & Lincoln Railway & Light Co., Ralston, Nebr.
Pingel, H. J., The Edward Ford Plate Glass Co., Rossford, Ohio
Potter, B. M., Bureau of Power & Light, Los Angeles, Calif.
Rastall, J. W., Western Electric Co., Inc., Philadelphia, Pa.
Ryan, V. A., Irvington Varnish & Insulator Co., Irvington, N. J.
Schwartz, C. E., Ohio River Edison Co., Toronto, Ohio
Servatzy, R. C., Commonwealth Edison Co., Chicago, Ill.
Smith, R. V., Boissevain, Va.
Stuedahl, L., Liberty Electric Co., Stamford, Conn.
Sundby, J., Brooklyn Edison Co., Brooklyn, N. Y.
Szabo, A., Jr., Public Service Corp. of N. J., Irvington, N. J.
Ten Brook, J. A., The Counties Gas & Electric Co., Norristown, Pa.
Vogeli, R., Stone & Webster, Boston, Mass.
von Brand, E. K., Priess Radio Corp., New York, N. Y.
Whipple, R. G., Electric Storage Battery Co., St. Louis, Mo.
Winetsky, M. C., Public Service Electric Co., Eliazbeth, N. J.
Yost, J. C., Radio Corp. of America; Rocky Point, N. Y.
Total 65

Foreign

Banerjee, A. C., Rampur State, Rampur, U. P., India
Barsdorf, L. W., General Electric Co., Kingsway, London, Eng.
Butherus, F. R., (Member), British Sangamo Co., Ltd., Middlesex, Eng.
Curley, J. C., Newcastle City Council, Hamilton, Aus.
Diaz, E., (Member), The British Thomson-Houston Co., Ltd., Rugby, Eng.
(Applicant for re-election.)
Huggett, W. H., Borough of New Plymouth, New Plymouth, N. Z.
Konstantinowsky, K., Cable Manufacturing Co., Ltd., Bratislava, Czechoslavakia, Europe
Levitsky, N. B., Andhra Valley Power Supply Co., Ltd., P. O. Karjet, Bombay, India
Painton, E. T., (Member), The British Aluminum Co., Ltd., London, Eng.
Richardson, R. P., Sydney Municipal Council, Sydney, Australia
Sargent, J. A. (Member) Raetihi Borough Council, Raetihi, North Island, N. Z.
Sonnenfeld, H., Cable Manufacturing Co., Bratislava, Czhecoslovakia, Europe
Total 12

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A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
H. P. Gibbs, Tata Sons Ltd., 24 Bruce Road, Bombay—1, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
Eiji Aoyagi, Kyoto Imperial University, Kyoto, Japan.
P. H. Powell, Canterbury College, Christchurch, New Zealand.
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W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

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(A list of the personnel of Institute committees may be found in the Sepembert issue of the JOURNAL.)

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APPLICATIONS TO MARINE WORK, L. C. Brooks
APPLICATIONS TO MINING WORK, F. L. Stone
GENERAL POWER APPLICATIONS, A. M. MacCutcheon
POWER GENERATION, Vern E. Alden
POWER TRANSMISSION AND DISTRIBUTION, Percy H. Thomas
PROTECTIVE DEVICES, E. C. Stone
RESEARCH, John B. Whitehead

A. I. E. E. REPRESENTATION

(The Institute is represented on the following bodies; the names of the representatives may be found in the September issue of the JOURNAL.)

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, COUNCIL
AMERICAN BUREAU OF WELDING
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AMERICAN ENGINEERING COUNCIL
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U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION
U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION
WASHINGTON AWARD, COMMISSION OF

A. I. E. E. SECTIONS AND BRANCHES

See the September issue for the latest published list. The Institute now has 49 Sections and 82 Branches.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Tachometers.—Catalog 44, 12 pp. Describes Brown indicating and recording tachometers. Brown Instrument Company, Philadelphia.

Turbine Signal Systems.—Bulletin 104-29-B, 12 pp. Describes Cory audible and visible signals, featuring turbine order systems. Chas. Cory & Son, Inc., 183 Varick St., New York.

Capacitors.—Bulletin, 24 pp. Capacitors for power factor correction on electric generating and distribution systems are described in this bulletin. General Electric Company, Schenectady, N. Y.

Air Filters.—Bulletin, 4 pp. "Clean Air for Electrical Equipment." Describes Midwest air filters for providing filtered air for electrical apparatus. Midwest Air Filters, Inc., 100 East 45th Street, New York.

Transformers.—Bulletin 2045, 40 pp. Describes Pittsburgh distribution transformers, single phase and polyphase. Contains diagrams showing test connections and a schedule of approximate dimensions of all sizes and voltages from 1½ kv-a. to 200 kv-a., 440 volts to 44,000 volts. Pittsburgh Transformer Company, Columbus & Preble Avenues, Pittsburgh, Pa.

Temperature Control Instruments.—Catalog 87, 40 pp. Describes Brown automatic temperature control instruments—indicating, recording, signalling and alarm types. The Brown Instrument Company, Philadelphia, Pa.

Petroleum Refining.—Bulletin, 26 pp. A brief description of organized and experienced engineering and construction service as applied to the petroleum industry. The J. G. White Engineering Corporation, 43 Exchange Place, New York.

Transformers.—Bulletin. "30 Years of Uninterrupted Service to the Electrical Industry" is the title of an interesting handbook on transformers. The bulletin is out of the ordinary in that the manufacturer does not mention his product in the text. It contains much practical engineering data and material for the electrical or consulting engineer and transformers operators in general. Kuhlman Electric Company, Bay City, Michigan.

NOTES OF THE INDUSTRY

W. N. Matthews Corporation, St. Louis, Mo., has revised all price and discount sheets covering its line of electrical specialties. Many reductions in prices have been made.

The Kuhlman Electric Company, Bay City, Mich., announces the appointment of the D. H. Braymer Equipment Company, 727 W. O. W. Building, Omaha, as district representative in Iowa and Nebraska, which will handle the Kuhlman line of power, distribution and street lighting transformers.

Allis-Chalmers Mfg. Company, Milwaukee, Wis., has placed on the market a complete line of 25 and 60-cycle squirrel-cage and slip-ring induction motors equipped with Timken tapered roller bearings. This type of bearing was decided upon after tests had shown its ability to withstand continued heavy radial and thrust loads without undue heating or appreciable wear.

The Electric Controller & Mfg. Company has appointed Eicher & Bratt as representatives for the sale of E C & M line of controller equipment in the states of Oregon, Washington and Alaska. In addition to handling the E C & M line, Eicher & Bratt also represent in their territory the Pittsburgh Transformer Company, Jewell Electrical Instrument Company, and the Electric Power Equipment Corporation.

The General Electric Company plans the immediate erection of a large warehouse and office at Santa Fe Avenue and 52nd Street, Los Angeles, Cal. The plant, which is to be used as a distributing center, will cost about $1,000,000, including land, buildings and equipment. One of the features of the office building is that it will be heated by electricity. The numerous departments of the company at present scattered over the city will be moved to the new location as soon as feasible. The building is expected to be ready the first of the year.

The Westinghouse Electric & Manufacturing Company has received a contract for power station equipment, including two 31,250 kv-a. turbine generators, and two 32,000 sq. ft. radial flow surface condensers with condensate pumps and air ejectors, from the Midland Utilities Company of Chicago. The equipment is to be used in the new station of the Calumet Power Company at Michigan City, Indiana, a subsidiary of the Midland Utilities Company. A feature which makes units differ somewhat from the ordinary type is the 600 pound throttle pressure and the 750 degrees total steam temperature at which the turbine operates.

Launching of the U. S. S. "Lexington."—The second of the United States Navy's new airplane carriers, the U. S. S. "Lexington," will be launched at noon, October 3, at the Fore River plant of the Bethlehem Shipbuilding Corporation in Quincy, Mass. As in the case of the U. S. S. "Saratoga," of which this boat will be a duplicate, the "Lexington" will be one of the largest ships ever launched on the western hemisphere and will excel the first line battleships of this country in propulsion power.

This will be the third United States airplane carrier. The only one now in service is the "Langley," named after the scientist noted for his practical investigation of aeronautics. That ship was rebuilt from the old collier, "Jupiter," the first vesel of the navy to be equipped with turbine electric drive.

The "Saratoga," launched this spring at Camden, N. J., is not yet in service. Originally, both the "Saratoga" and "Lexington" were to have been battle cruisers but the modification of the American naval program, due to the decisions reached at the conference on the limitation of armament, led to the conversion of these battle cruisers into airplane carriers.

As a naval vessel, the "Lexington" (with the exception of its twin, the "Saratoga") will be the longest in the world. Its length will be 874 feet and its beam, 105 feet. The output of its electric generating equipment will be 180,000 horse power—greater than the combined rated output of the six electrically driven capital ships now in commission; viz., the "New Mexico," "California," "Tennessee," "Maryland," "Colorado" and "West Virginia."

The complete electrical equipment for the "Lexington," as in the case of the "Saratoga," will be furnished by the General Electric Company. The propulsion apparatus will consist of four 35,200-kilowatt turbine generators, supplying current to eight 22,500-horse power motors. The turbines will be operated by steam from 16 oil-fired boilers.

The motors will be connected in pairs to each of the four propeller shafts. The total energy thus delivered, to each shaft being 45,000 horse power—sufficient to turn the propeller blades at a rate of 317 r. p. m. and to propel the ship at the rate of 33 knots, or approximately 39 miles an hour.

In addition to the propulsion machinery, there will be provided six 750-kilowatt, direct current, auxiliary turbine generators which will furnish current for all electrical purposes except main propulsion. Among other uses to which this electricity will be put will be the operation of the steering gear, anchor windlass, ventilation fans and lighting systems.